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Measuring the Corrosion Rate of Reinforcing Steel in Concrete

U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards
National Measurement Laboratory
Center for Materials Science
Metallurgy Division
Washington, DC 20234

April 1984

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E. Escalante, M. Cohen, A. H. Kahn

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U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, *Secretary*
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

MEASURING THE CORROSION RATE OF REINFORCING STEEL IN CONCRETE

The deterioration of concrete bridge decks as a result of corrosion action on the reinforcing steel is a serious and costly problem to the nation (1). It is recognized that this corrosion is caused by the diffusion of chloride ions into the concrete resulting in the breakdown of the passive iron oxide film that normally protects the steel. The corrosion product that forms generates sufficient pressure to crack the concrete allowing moisture, oxygen, and more chloride to enter, further accelerating the deterioration process (2).

Methods have been developed that: a) block the chloride from coming in contact with the steel, (b) stop the chloride from entering the concrete, (c) remove the chloride from the vicinity and (e) others, such as cathodic protection, which modify the reactions at the surface of the steel (3-7). All of these approaches require some method to evaluate their effectiveness, and the most direct method is to measure the corrosion rate of the steel before and after a modification to the concrete.

Procedure

The plan for this study is divided into the following five phases which are: A literature review, preliminary studies, measurements in concrete, field measurements, and the development of a microprocessor system. More than half of these phases have been accomplished and reported as will be described.

Phase I. Literature Review - At the outset, a literature search was undertaken to identify the information available on the corrosion of steel in concrete and methods for measurement. A total of 394 papers, reports, and talks from 1964 through 1978 were identified on the subject, and are indexed under subject and author (8). The Subject Index was further subdivided into six subgroups such as general survey, factors affecting corrosion, measurement

techniques, protection techniques, concrete design, and related fields. In the Author Index, the references are listed alphabetically by author.

A study of this literature revealed several interesting facts. For example, it was found that over thirty references discussed the effect of chloride on corrosion, but only one reference discussed the effect of oxygen content. Furthermore, the effect of moisture was considered in just four of these references. Not one study on the corrosion of steel in an alkaline environment was found. Clearly, most of the attention had been directed towards the effects of chloride.

Phase II. Preliminary Studies - From the information gathered through the literature search, it was evident that more information was needed on the effects of oxygen, pH, and moisture, and therefore an experimental program was designed to evaluate these factors. Three environments were used on this phase of the study, and these were alkaline solutions of $Ca(OH)_2$ with controlled oxygen, Cl^-, and pH; wet sand/salt mixtures; and mortar (9).

Flat steel specimens 100 x 20 x 1 mm were immersed in controlled solutions and the initiation time for visible corrosion was noted. At a pH of 10.5 or less, corrosion started immediately on immersion. However, as the pH was raised to 12, initiation times increased to 200h, and at higher pH corrosion did not occur during the period of the experiment. The experiment was repeated in the presence of chloride, and it was found that chloride did reduce the initiation time to corrosion but otherwise had little effect. Once initiated, the corrosion rates were constant in all cases. Not surprisingly, the oxygen content of the solution had a large effect on the corrosion rate of the steel with lower concentrations leading to lower corrosion rates.

Further experiments were carried out as described which indicated that the interaction of oxygen, pH, and chloride is more complex and in combination can develop conditions that lead to corrosion even at high values of pH. Figure 1 is a summary of these data showing these three parameters. Illustrated is a three dimensional figure with boundaries within which corrosion does not occur. However, outside of this boundary corrosion of steel is observed. For example, where it was shown earlier that chloride or oxygen acting alone could not cause corrosion of steel at a pH of 12.5, this figure reveals that at an oxygen concentration as low as 2 ppm and at a Cl^- concentration of 6 mol/l, corrosion does occur, and can also develop at lower concentrations of Cl^- at higher oxygen contents.

To observe the effect of moisture on the corrosion of steel, specimens were imbedded in a mixture of sand, $Ca(OH)_2$, and NaCl. The mixture was held in small perforated crucibles in an atmosphere of flowing air with controlled moisture content. This configuration allowed the specimens to be removed for weight loss determination during the course of the experiment. Specimens in a moisture saturated sand mixture did not corrode, but during the same period, specimens in a dry mixture began to corrode almost immediately as moisture was introduced. However, the corrosion rate of these specimens decreased steadily as moisture content of the sand mixture increased; and at saturation, the corrosion ceased. Clearly, the degree of moisture, which affects oxygen concentration, plays a very important role as expected, but the cessation of corrosion at saturation was not anticipated.

After the study of steel in solutions and in sand mixtures was completed, the work was extended to include steel in mortar. Specimens as described above were cast with a 5 mm cover of chloride-containing mortar. After 24h, half of the specimens were immersed in a $Ca(OH)_2$/NaCl solution and half

were allowed to dry for one week before immersion. The corrosion current of each specimen was determined by polarizing the specimen from -10 to +10 mV with a potentiostat and plotting the overvoltage as a function of the polarizing current. As in the case of the sand mixture, the corrosion of the steel in mortar that was kept continuously wet was near zero, but the specimens that were allowed to dry for one week, and then immersed, initially developed a high corrosion rate that decreased with time to a very low value.

In summary, these studies have shown that at low concentrations of O_2 and Cl^-, pH controls the initiation of corrosion. But as O_2 and Cl^- increase, corrosion can initiate even at a pH of 12.5. It is hypothesized that in the moisture saturated concrete, the concentrations of Cl^- and oxygen are sufficiently low for conditions to exist within the "no corrosion" boundary of Figure 1. However, as the concrete dries, the Cl^- concentration in the pore water eventually increases to saturation. This drying process also allows oxygen to diffuse more rapidly through the concrete setting up conditions outside of the "no corrosion" boundary where corrosion of steel does take place. Once corrosion is initiated, the pH is reduced at the anodic areas by the corrosion reaction, making it easier to reinitiate corrosion in future times when moisture and oxygen are available.

Phase III. Measurements in Concrete - The purpose of this portion of the work was to compare several polarization techniques for measuring the rate of corrosion of steel in concrete(9). All polarization techniques are essentially the same in that the measurement is based on the observation that the polarizing current necessary to change the potential of a metal in an electrolyte, in this case concrete, is directly related to the rate of corrosion of the metal. The techniques differ only by how this change

in potential is achieved. Initially, four techniques were used in this study and are described as follows: Stern and Geary consider the derivative of the potential of the specimen versus the applied current for deviations from the corrosion potential not greater than 10 mV (10). This slope is related to the corrosion current, I_{corr}, by the relationship:

$$\lim_{dE \to 0} \frac{dE}{dI} = \frac{b_a \cdot b_c}{2.3(b_a + b_c)I_{corr}}$$

where b_a and b_c are the anodic and cathodic Tafel Slopes respectively. For calculation of the corrosion current, I_{corr}, values for the Tafel slopes must be obtained from other sources, or by trial and error for the best fit to the data. In this case ΔE was 6 mV and the assumption made that $b_a = b_c = 100$ mV. Thus:

$$I_{corr} = \frac{21.7\Delta I}{\Delta E}$$

The second technique used is an empirical approach described by Schwedtfeger in which I_{corr} is determined from the change in slope of the polarization curve (11). The cathodic corrosion current, I_p, and the anodic corrosion current, I_q, are found at this "break" in the curve, and the corrosion current is then calculated from:

$$I_{corr} = \frac{I_p I_q}{I_p + I_q}$$

The technique requires that polarization, ΔE, extend over a range of ±100 mV so that the "breaks" in the polarization curve may be observed.

The three point method of Barnartt is the third technique that has been used (12). Three voltage/current data points are measured along the polarization curve, and from this b_a, b_c, and I_{corr} are calculated as follows. If the first potential point is at ΔE, then the second and third are at $2\Delta E$ and $-2\Delta E$ respectively. The resulting currents at each potential are measured and substituted into the ratios

$$r_1 = I_{2\Delta E}/I_{-2\Delta E}$$

and $$r_2 = I_{2\Delta E}/I_{\Delta E}$$

which in turn are related to each other through the quadratic equation

$$U^2 - r_2 U + r_1 = 0$$

The roots of this equation are

$$\exp \frac{2.3\ \Delta E}{b_a} \quad \text{and} \quad \exp \frac{2.3\ \Delta E}{b_c}$$

from which b_a and b_c are calculated. Using the relationship of I/I_{corr} versus ΔE, the corrosion current for the process is found.

The fourth technique is a computer analysis of polarization data developed by Mansfield (13). The computer makes a best fit analysis to theoretical curves generated from the Stern-Geary equation for different values of Tafel slopes and in this way b_a, b_c, and I_{corr} are found.

Each of the polarization techniques described employs a three electrode system having the steel specimen as one electrode, a voltage reference as a second electrode, and a counter electrode as a third electrode from which polarizing current is applied to the specimen. The circuit used for these measurements is Holler's (14) which incorporates a Wheatstone bridge for IR compensation as illustrated in Figure 2. The IR compensating design takes advantage of the fact that when a polarizing current is applied to the specimen, its rate of change in potential due to polarization is very small compared to the rate of change in potential due to IR. By repeated applications of current of short duration (e.g. 0.5s), and by adjusting the Wheatstone balancing resistance, the IR component is compensated. Once this balance is achieved, then the polarizing potential, free of IR, can be measured for all values of applied current.

Small concrete slabs 55 x 30 x 5 cm were cast each with three imbedded 1.27 cm diameter steel rods. Two small stainless steel rods were also encased in the concrete and were used to determine the resistivity of the slab. The concrete was treated in two ways. Four of the slabs were cast with 0.06 parts NaCl to one part cement (38.4 lbs NaCl/cu.yd), and the remaining eight slabs were cast without Cl^-. After curing for approximately thirty days, two of the Cl^- free slabs were immersed in a saturated solution of NaCl for six days, withdrawn, and left in a dry laboratory atmosphere. Two other slabs were immersed in a 3.5% NaCl solution for 24h, withdrawn, and also left in a laboratory atmosphere. Corrosion measurements showed that steel specimens in Cl^- free slabs developed very low corrosion rates (<0.007 mg/dm^2/day). However, those slabs with Cl^- in the concrete immediately developed a corrosion rate of 4.4 mg/dm^2/day or more than two orders of magnitude greater than those in Cl^- free concrete. Figure 3 illustrates the decreasing rate of corrosion as the concrete dried. In the case where the chloride free concrete slabs were immersed for six days in a sodium chloride saturated solution, the corrosion rate increased by over an order of magnitude within a few hours as shown in Figure 4. The second group of chloride free concrete slabs that were immersed for only 24h in a solution of 3.5% NaCl behaved similarly to those immersed longer in a more concentrated solution. The average weight loss of steel on these specimens, based on electrochemical measurements, was 0.33 mg/dm^2/day. The resistivity of the concrete was also measured with time, and the data reveal that the resistivity decreases as moisture increases. However, the effect of immersion on the corrosion rate is much greater than its effect on the resistivity of the concrete. As the concrete dries and the resistivity increases above 7,000 ohm-cm, the resistance appears to have a direct influence on the degree of corrosion observed.

Weight losses were calculated from the electrochemicaly determined corrosion currents measured as a function of time, and were compared to gravimetric weight loss measurements on the same cleaned steel rods. A comparison of the data from the four electrochemical techniques described is shown in Table 1 and indicates that all methods overestimated the weight loss of steel. The Stern-Geary method overestimated weight loss by 17% while Schwerdtfeger's, Mansfeld's, and Barnartt's techniques overestimated weight loss by 40%, 56%, and 83% respectively. Since the differences in the corrosion rates between a corroding and a non-corroding system are over an order of magnitude, then even the data with an overestimation of 83% will reveal the existence of high corrosion.

In summary, the data indicate that the corrosion of steel in chloride free concrete is negligible and less than 0.007 $mg/dm^2/day$ while the corrosion rate in chloride contaminated concrete is more than an order of magnitude greater with an average of 0.33 $mg/dm^2/day$, but can be as high as 4.4 $mg/dm^2/day$. Comparison of the gravimetrically determined weight loss to the weight losses calculate from the polarization data indicates that the electrochemical measurements overestimate weight loss by 17% to 83%. However, even with an overestimation of 83%, the polarization techniques will differentiate between a corroding and a noncorroding condition of steel in concrete.

An important part of this study is the characterization of the current distribution during polarization measurements. This distribution must be known in order to determine the area of the steel being polarized which, in turn, makes it possible to calculate a corrosion current density or weight loss of steel per unit length of steel bar.

Under controlled laboratory conditions, determining this area is not a serious problem since the specimens are small and the geometry of the

electrodes can be arranged so that the entire specimen electrode is polarized with a uniform current. But in extending these polarization measurements to a bridge deck we are faced with limitations brought on by the relatively large size of the structure. The major constraint being that, unlike our small slabs in the laboratory, we cannot polarize the entire bridge at once, but can only polarize a small area at a time, and it is this area that must be characterized.

The experimental procedure used is simple in principle. In an attempt to simulate the large scale geometry in a small slab, it was decided to use a long line specimen in concrete and polarize it from a point or small line current source. The potential of the steel in the concrete would be monitored by reference electrodes positioned along its length. Three variables were considered as having an effect on the distribution of the current, and these are the distance between the counter electrode and the specimen, the amount of current applied, and the resistivity of the concrete.

Using small concrete slabs similar to those described earlier, a new geometric arrangement of electrodes was designed as shown in Figure 5. As before, the steel rod is imbedded horizontally along the length of the concrete slab. The counter electrode is a small diameter (3 mm) rod positioned vertically adjacent to the steel specimen. Three counter electrodes at different distances (1,2,4cm) from the specimen are illustrated. Ten reference electrodes, imbedded in the concrete, are located 8.5 cm apart along the length of the steel rod and 2 cm from its surface. This arrangement of electrodes allowed a polarizing current to be applied to the steel specimen from a small vertical line source. Any changes along the length of the specimen are detected by the reference electrodes. Measurements were

made using one of the three counter electrodes. The resistivity of the concrete was controlled by controlling its moisture content. During an experimental run, the potential along the length of the specimen was measured before any current was applied. Subsequent potential measurements were made with reference to this initial base potential. The polarizing current was increased in increments and the potential measurements repeated until a maximum of approximately 10 mV was achieved. Initial measurements were made manually using the Holler bridge circuit for compensation of IR. More recent measurements were made using a computer controlled system which applies a cycling direct current of 5 seconds on and 0.25 seconds off. The potential of the specimen was then read during the current off cycle so that the IR component was zero. Figure 6 illustrates the distribution of current as indicated by the change in potential along the length of a steel rod in concrete. This curve is a measure of the extent of current distribution along the length of a horizontal steel rod when the current source is a small vertical rod in the concrete. The shape of the curve is an indication of how uniformly the current is distributed within the polarized area. This type of data have been obtained as a function of counter electrode distance, applied current, and resistivity of concrete. Preliminary analysis of the data indicates that, as expected, the extent of the current distribution decreases as the resistivity of the concrete increases, and the general shape of the current distribution curve does not appear to be affected. In addition, as the electrode distance is decreased, the area of steel rod polarized also decreases. The largest effect observed is that of the applied current. As the current is increased, the area of distribution

increases. But perhaps the most important observation is that current distribution is very limited and 90% of the current encompasses a distance of less than 10x the distance between the specimen and the current source electrode.

A mathematical model has been developed that takes these variables into consideration and generates a current distribution curve along a cylinder from a point source in free space as follows. The electric current distribution in a conductive medium containing electrodes held at arbitrarily fixed potentials may be obtained by a standard application of potential theory. For the case of an infinitely long cylindrical conductor embedded in an electrolyte with a point source of current at a fixed distance from the cylinder, an extension of the formulas given by Jackson gives a complete solution for the current distribution in the electrolyte (15).

The following geometric arrangement is treated as illustrated in Figure 7. Consider an infinitely long metallic cylinder of radius a, held at ground potential, and at a distance, d, from the axis of the cylinder, a point electrode emits a total current I_0. By application of the methods stated above, the current density at any point, P, on the surface of the cylinder is described.

$$J(Z,\theta) = \frac{I_0}{\pi^2 a} \sum_{m=0}^{\infty} \frac{\cos m\theta}{\varepsilon_m} \int_0^{\infty} dk \cos kz \frac{K_m(kd)}{K_m(ka)}$$

where

$J(Z,\theta)$	=	Current density at point P on the cylinder
I_0	=	Total current emitted by source at d
m	=	Integer index for summation
k	=	Variable of integration
ε_m	=	2 for m = 0; 1 for m > 0
$k_m(x)$	=	A modified Bessel function of the second kind, order m, argument x, see ref. (16)

Although this formula is a closed mathematical expression with a precisely defined meaning, its evaluation to a specified accuracy requires numerical integration of a function which is rapidly oscillating and the summation of a convergent series. Use of digital computing methods to produce graphical or tabular representation of the results is essential. A preliminary evaluation of the function, illustrated in Figure 8, demonstrates that it does follow the general shape of the measured data. Further analysis of this function and its correlation to the data is required for a more accurate assessment of their relationship.

Phase IV. Field Measurements - After gaining some experience in performing the corrosion
measurements on concrete slabs in the laboratory, the measurements were extended to the field on an operating bridge deck. With the cooperation of the Virginia Highway Department arrangements were made to perform corrosion rate measurements on a bridge deck (Number 2063) on Interstate 66 near the Washington, DC Beltway. The primary objective of this portion of the study was to evaluate the background electrical noise and determine whether the measurements could be made.

Measurements were made on two separate decks that were a few hundred meters apart. Two sets of measurements were made on a seven year old deck (area A) repaired and widened (area B) eighteen months earlier and now in use, and one set was made on a deck (area C) over a year old but not yet opened to traffic. The major difference between the two decks is that the older deck with its new widened section had been exposed to de-icing salts while the new deck, barricaded to traffic, was not salt contaminated.

During the measurements, electrical contact was made to the steel rebar with modified locking pliers. The counter electrode was a 500 cm^2 rectangle of aluminum foil wrapped in a towel wetted with a saturated solution of

$Ca(OH)_2$. A 6-cm diameter hole was cut out of the center of the counter electrode to accommodate the $Cu/CuSO_4$ reference electrode positioned at this point on a small wetted sponge. Using the Stern-Geary technique and the Holler bridge circuit, measurements were made at areas A, B, and C, and a portable Tetronix Model 214 oscilloscope was employed to monitor the background electrical noise.

The background electrical noise was found to be a very high frequency signal beyond the kilohertz range of our instrument, but more importantly, it was of very low amplitude and less than 1 mV. Apparently the steel structure of the deck acts as a very good antenna for radio frequency radiation. The corrosion measurements revealed that area A on the 7 year structure developed a corrosion current of 9.8 μA, while area B on the recently widened section of the same structure had a corrosion current of 6.9 μA. The new deck not open to traffic displayed the lowest corrosion current of 1.2 μA. Thus, though the data could not be verified by examination of the steel, it did seem reasonable. That is the oldest contaminated structure did display the highest corrosion and the new uncontaminated deck the lowest corrosion. Furthermore, it was found tnat the measurements could be made and that background interference was negligible.

Phase V. Microprocessor System - It is recognized that the corrosion measurements are tedious, time consuming, and require some knowledge of the concepts involved, and because these measurements lend themselves to automation, the ultimate goal of this project is to develop an instrument that will make these measurements automatically. Field measurements would then be performed with a microprocessor controlled device which would relieve the operator of most of the detailed adjustment, data acquisition, and calculations required. This device is to be as simple

allowing minimally trained personnel to perform the measurements. A description of the design of such a device follows.

The instrument is designed around a set of commercially available microcomputer printed circuit cards. These are based on a MC 6809 microprocessor circuit giving the system a very capable and powerful controller. The modules used in the system are:

1.) The processor card

2.) Battery backed-up memory

3.) Serial, parallel, and timing card

4.) Analog to digital converter

5.) Digital to analog converter (modified)

6.) Vacuum fluorescent display

In addition to these commercial cards, several other cards have been constructed at NBS, and serve two functions. First, to provide an interface between the user and the system are the following:

1.) Keyboard and display panel

2.) Test and keyboard control

Second, to interface the instrument to the experimental cell, these cards were constructed:

3.) Voltage to current converter

4.) Input amplifier and distribution card

Schematics of these cards and the modification to the digital to analog converter are illustrated in Figures 9 through 13.

The instrument operates in the following manner. At turn on, if the test switch is on, the unit is in a display test mode. The system will not function except for the display which will demonstrate the full character

set on a character by character basis. When the test switch is deactivated, followed by a reset, the system goes into operational mode and instruction messages appear on the display.

In the operational mode, the processor requests information from the user, and when all necessary parameters are stored, sets up the system for zero levels and enters a wait state until the operator lets it know that final hook up to the cell is complete. This information is transmitted to the instrument by pressing the "RUN" key thereby activating the microprocessor to begin data acquisition. Output current is generated by a precision voltage to current converter. Voltage driving this converter is derived from a 10 bit digital to analog converter under control of the processor. The full scale output current range is also selectable by the processor software. Input potentials are measured by a 12 bit analog to digital converter. Three channels are used in this measurement. One channel measures the current applied, another the counter electrode to working electrode potential, and the third the reference electrode to working electrode potential where the working electrode is steel in the concrete. The data are then saved in a battery backed up memory remaining there until deliberately erased. When data acquisition is complete, calculations are performed and the results displayed. A permanent record can then be printed out and the data erased, or another experiment can be performed while the data is saved for later printing. The software has been developed as a system of modular routines, the majority of which are single function stand alone subroutines (Appendix A). Links between modules have been made absolute, and therefore the overall program is not relocatable. However, relocation can be put into the system with little difficulty, if it should prove desirable. The software design is such that changes to the

measurement technique can be made by changing 3 or 4 of the modules. Such a change is necessary to the present modules since interfacing problems have resulted in an error in the measurements. These changes are in the process of being implemented.

Summary

This National Bureau of Standards study has revealed the following information.

1.) A total of 394 papers, reports, and talks from 1964 to 1978 were found pertinent to the subject of the corrosion of steel in concrete. A study of this literature indicated that information was lacking on the effect of oxygen, pH, and moisture.

2.) Oxygen concentration, chloride concentration, and pH have been found to control the initiation of the corrosion of steel in concrete. Moisture content of the concrete also plays an important role through its effect on the concentration of oxygen and chloride.

3.) The comparison of four polarization techniques for measuring the corrosion of steel in concrete reveals that all the techniques overestimated the weight loss from 17 to 83%. Current distribution measurements indicate that the extent of current distribution along a steel bar in concrete is very limited and of the order of 10 times the distance between the specimen and the current source. A mathematical model describing this current distribution is being developed.

4.) Corrosion rate measurements on operating bridge decks verify that polarization techniques can be used in this situation, and furthermore, background electrical noise is negligible.

5.) A microprocessor controlled instrument for making corrosion rate measurements has been designed and constructed. However, complications in interfacing the cards have developed requiring a change in its design. These improvements are in the process of implementation.

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TABLE 1

Comparison of Weight Loss Determined Gravimetrically

to

Weight Loss Calculated From Polarization Data

Technique	Weight Loss, mg	Overestimate %
Gravimetric	147	--
Stern-Geary	172	17
Schwerdtfeger	206	40
Mansfeld	230	57
Barnartt	269	83

FIGURES

1.) A three dimensional plot of Cl^- concentration, oxygen concentration, an pH showing the regions of corrosion and no corrosion.

2.) A simplified schematic of the Holler bridge circuit as used in a manual measurement of corrosion rate of steel in a concrete slab.

3.) A plot of corrosion current and resistivity versus time for steel in salt contaminated concrete.

4.) A plot of corrosion current and resistivity versus time for steel in concrete contaminated with salt after curing.

5.) Geometry of electrodes for current distribution measurements.

6.) A plot of current distribution along a steel bar in concrete as indicated by its change in potential.

7.) Geometry of electrodes used in model of the current distribution calculation.

8.) A plot of one half of the current distribution along an infinitely long cylinder as calculated from the model.

9.) Schematic diagram of the keyboard and display panel circuit.

10.) Schematic diagram of the keyboard and display panel circuit.

11.) Schematic diagram of the keyboard scanner circuit.

12.) Schematic diagram of the voltage to current converter circuit.

13.) Schematic diagram of the input amplifier and distribution circuit.

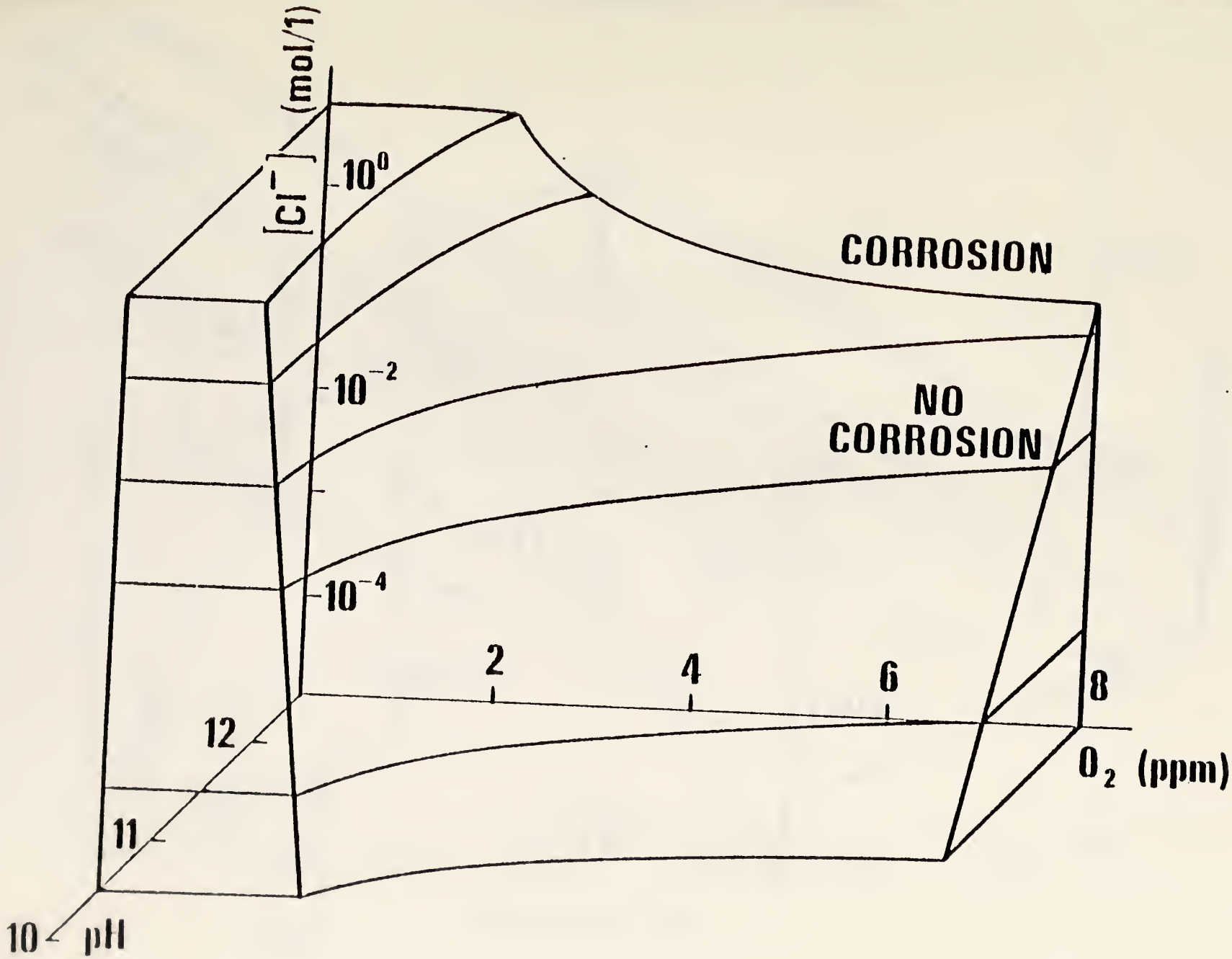

[Cl⁻] (mol/l)
10⁰
10⁻²
10⁻⁴
CORROSION
NO
CORROSION
2
4
6
8
O₂ (ppm)
12
11
10
pH

Figure 1

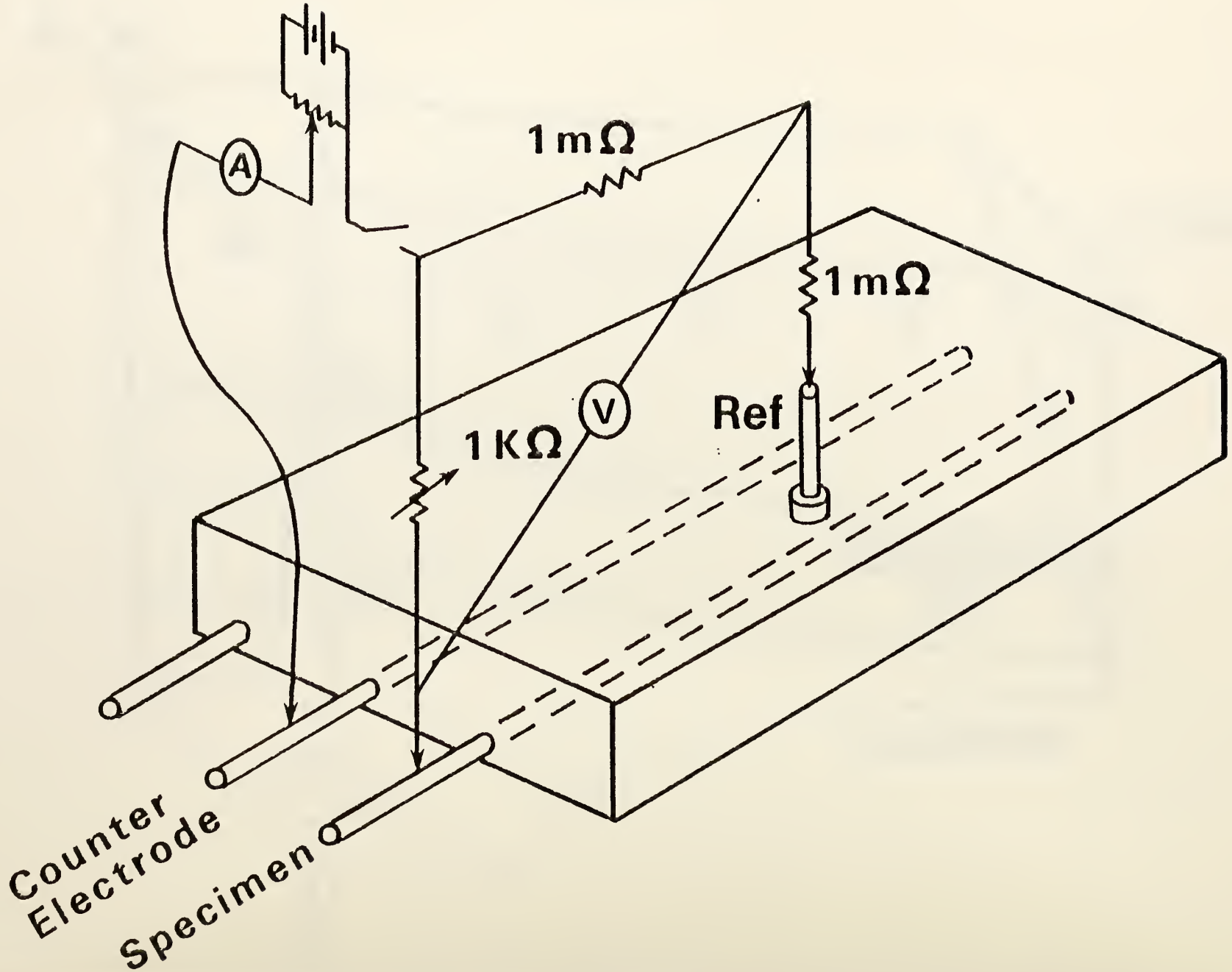


Figure 2

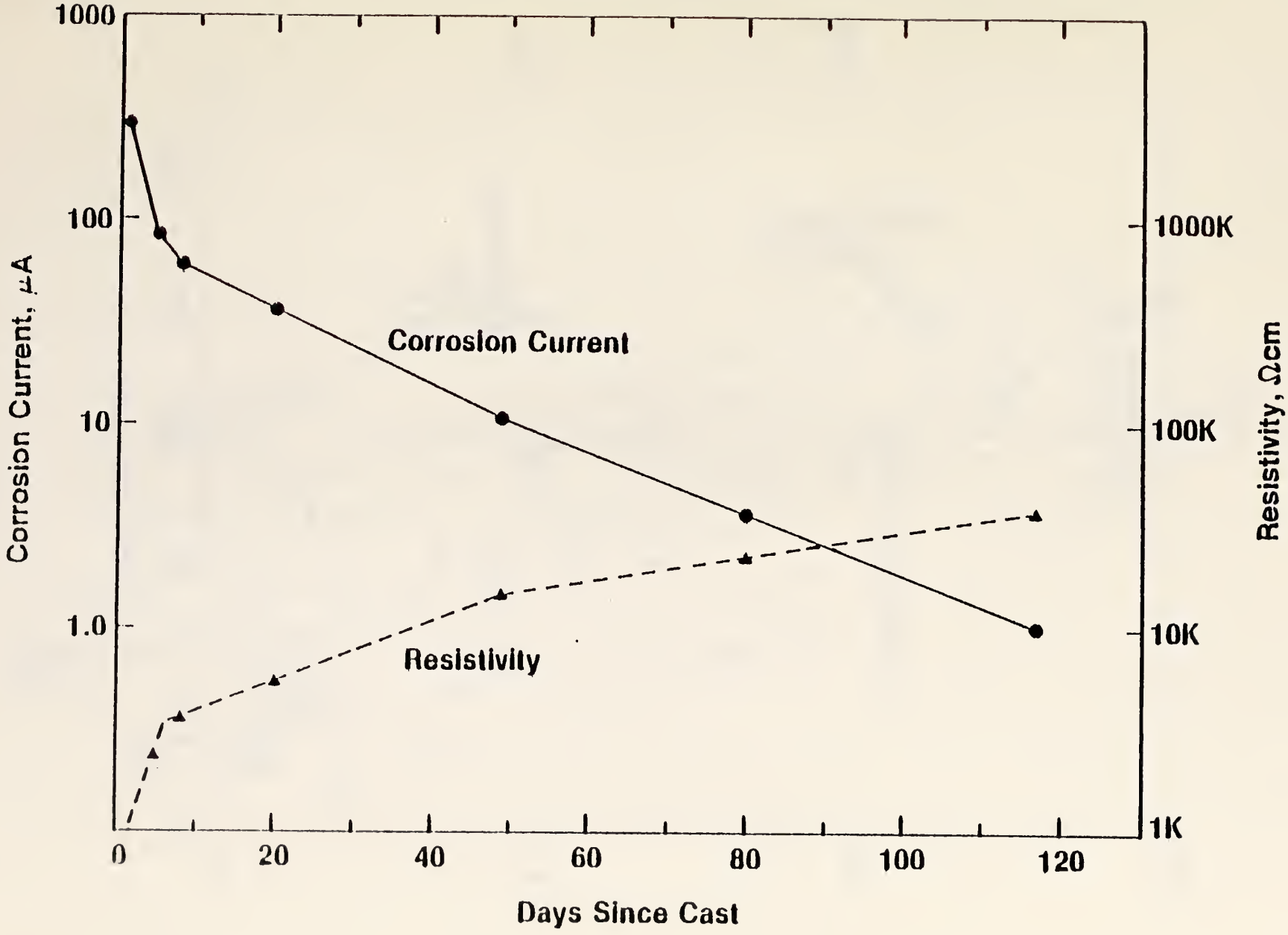

1000
100
10
1.0
Corrosion Current, μA
Corrosion Current
Resistivity
1000K
100K
10K
1K
Resistivity, Ωcm
0
20
40
60
80
100
120
Days Since Cast

Figure 3

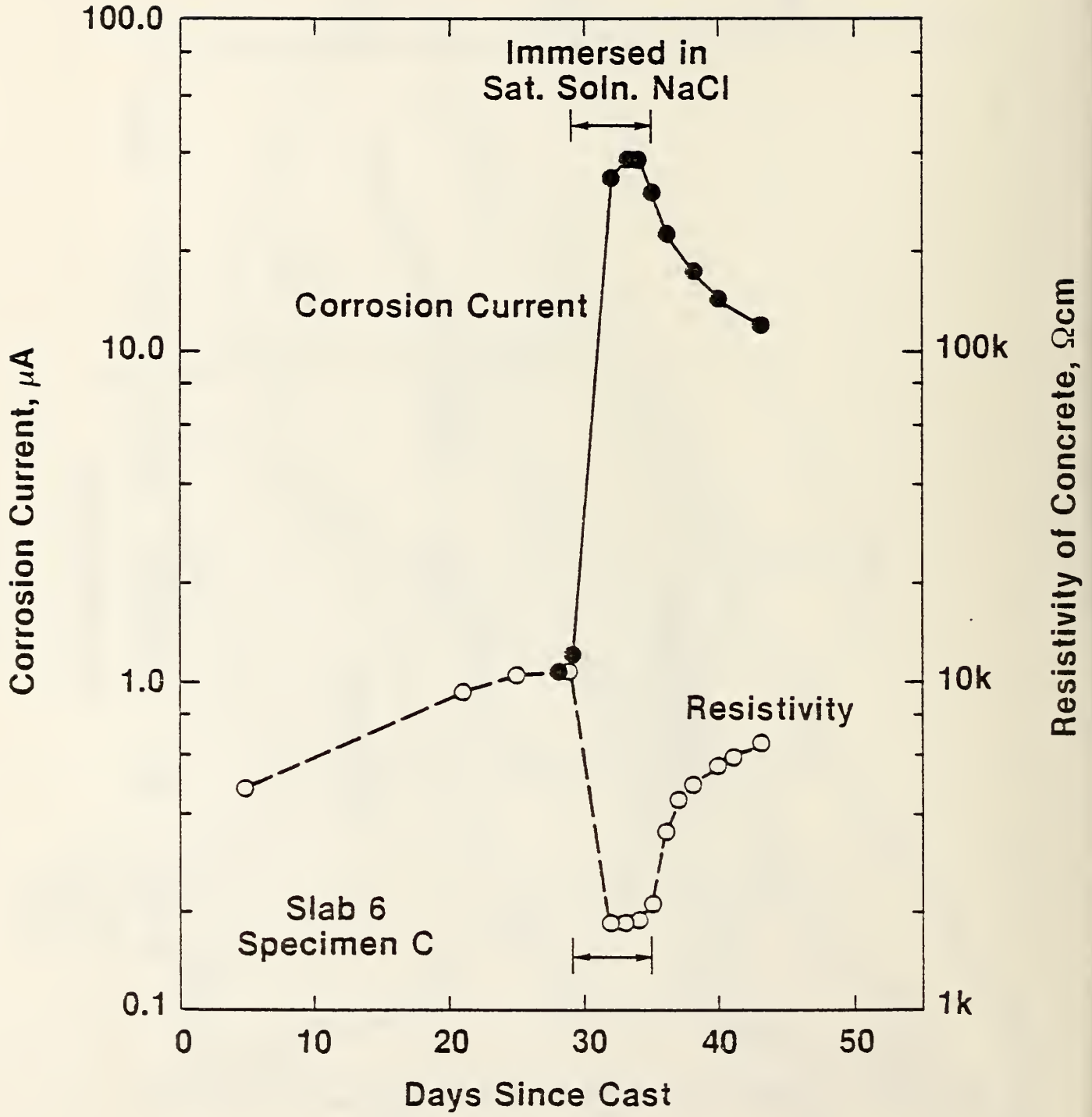

100.0
10.0
1.0
0.1
Immersed in
Sat. Soln. NaCl
Corrosion Current
Resistivity
Slab 6
Specimen C
Corrosion Current, μA
Resistivity of Concrete, Ωcm
100k
10k
1k
0
10
20
30
40
50
Days Since Cast

Figure 4

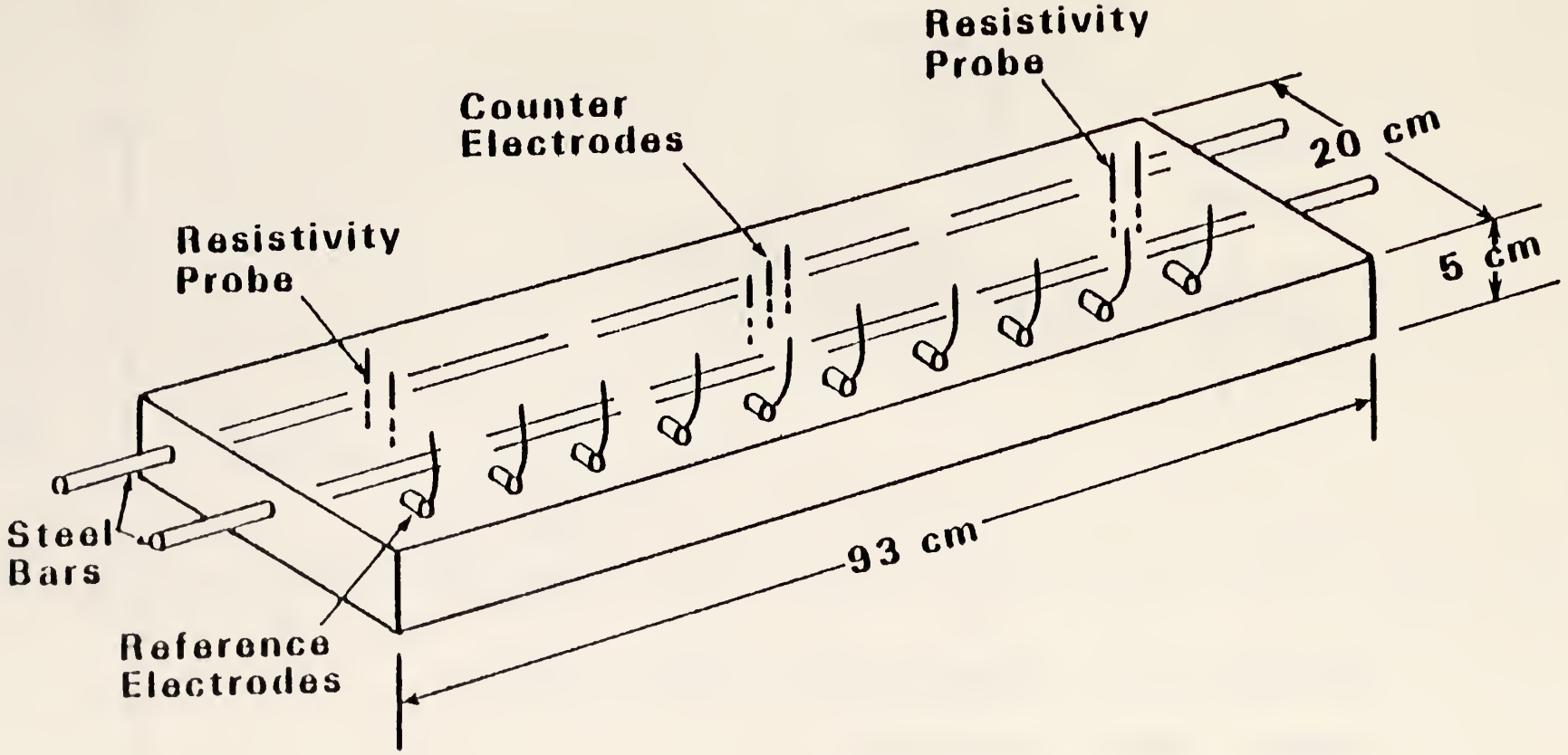

Resistivity
Probe
Counter
Electrodes
20 cm
Resistivity
Probe
5 cm
Steel
Bars
93 cm
Reference
Electrodes

Figure 5

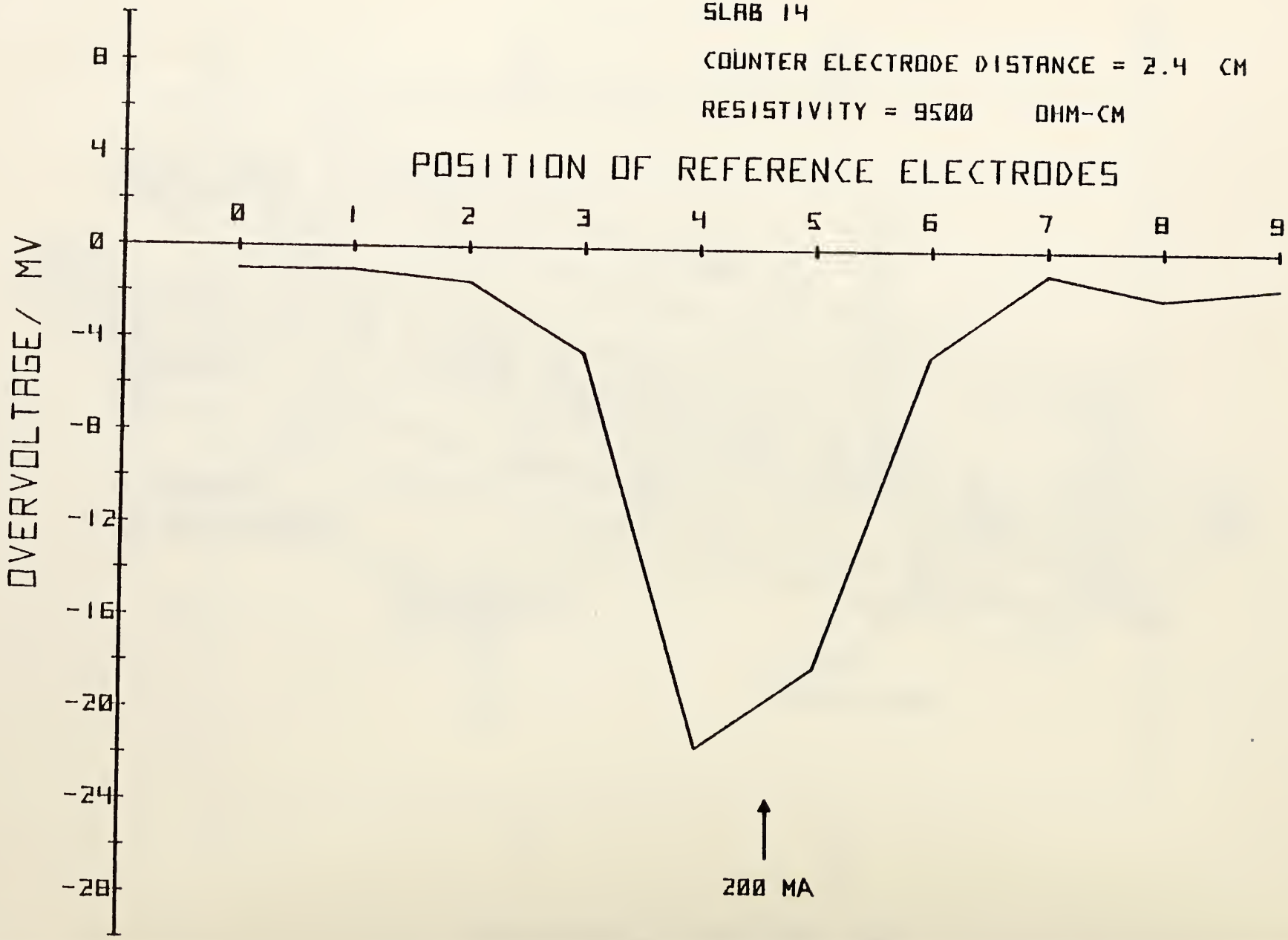

SLAB 14
COUNTER ELECTRODE DISTANCE = 2.4 CM
RESISTIVITY = 9500 OHM-CM
POSITION OF REFERENCE ELECTRODES
OVERVOLTAGE/ MV
8
4
0
-4
-8
-12
-16
-20
-24
-28
0
1
2
3
4
5
6
7
8
9
200 MA

Figure 6

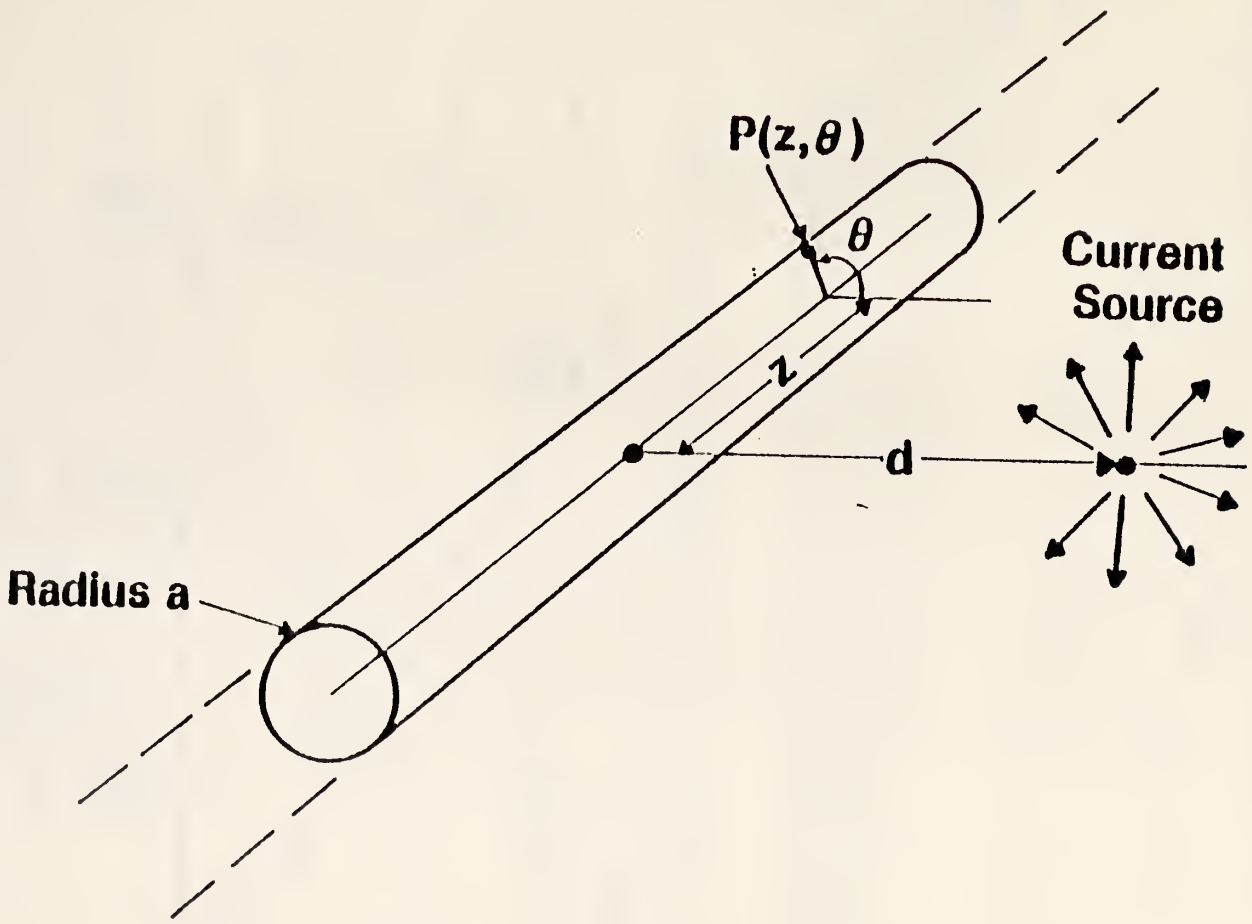
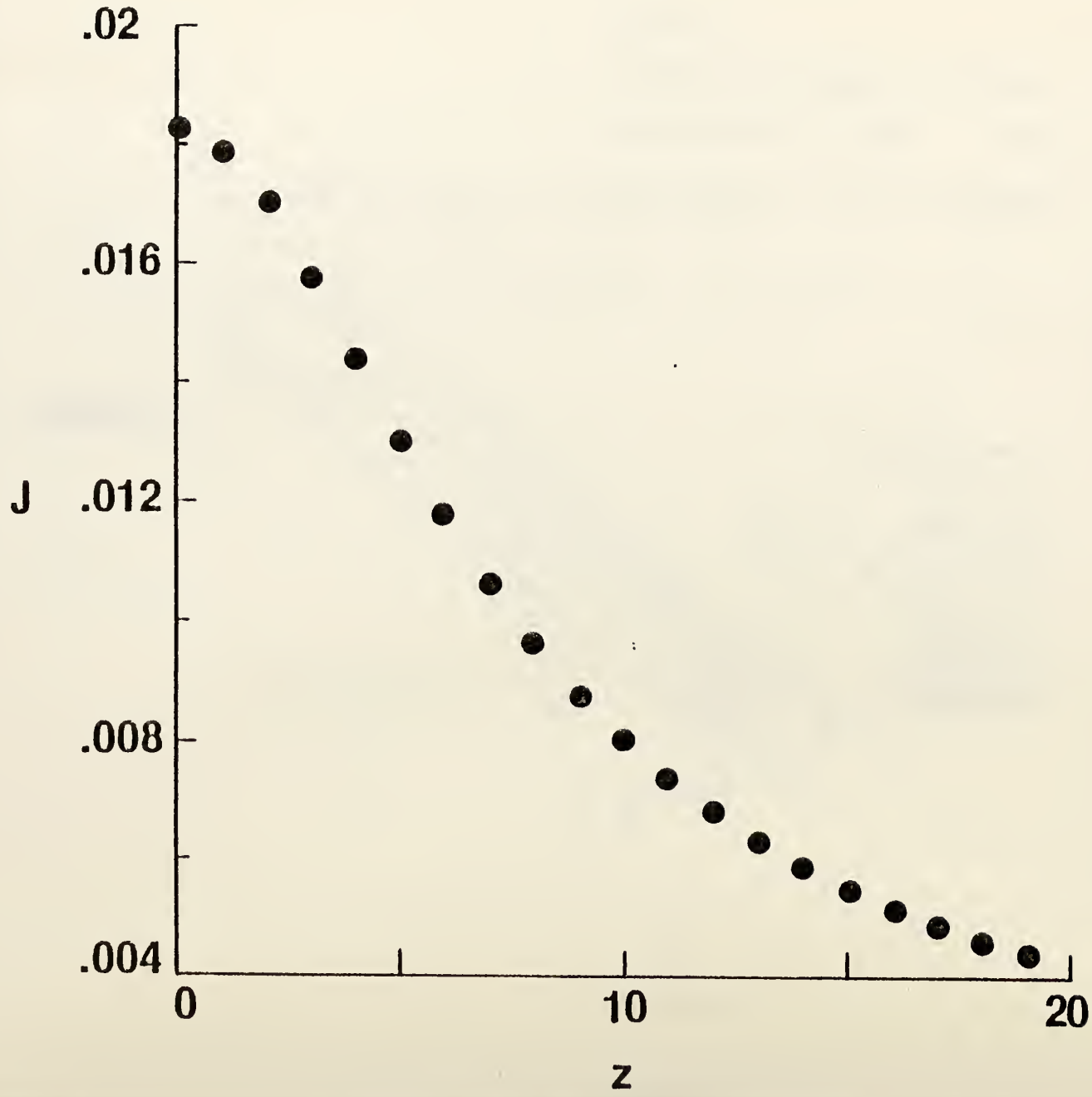


Figure 7


.02
.016
J .012
.008
.004
0
10
20
z

PANEL WIRING

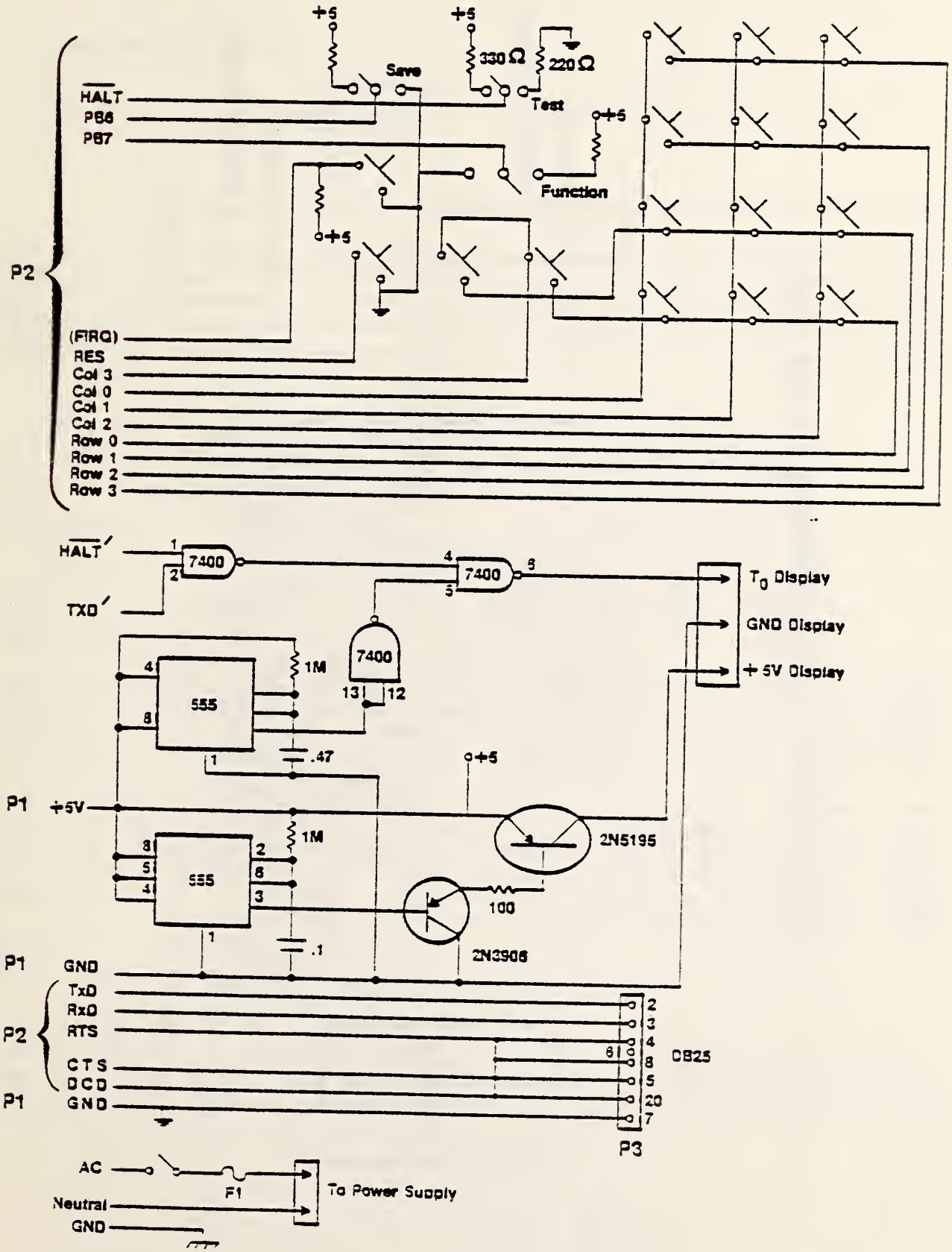


Figure 9

Modification to 1614 Module (10 Bit DAC)

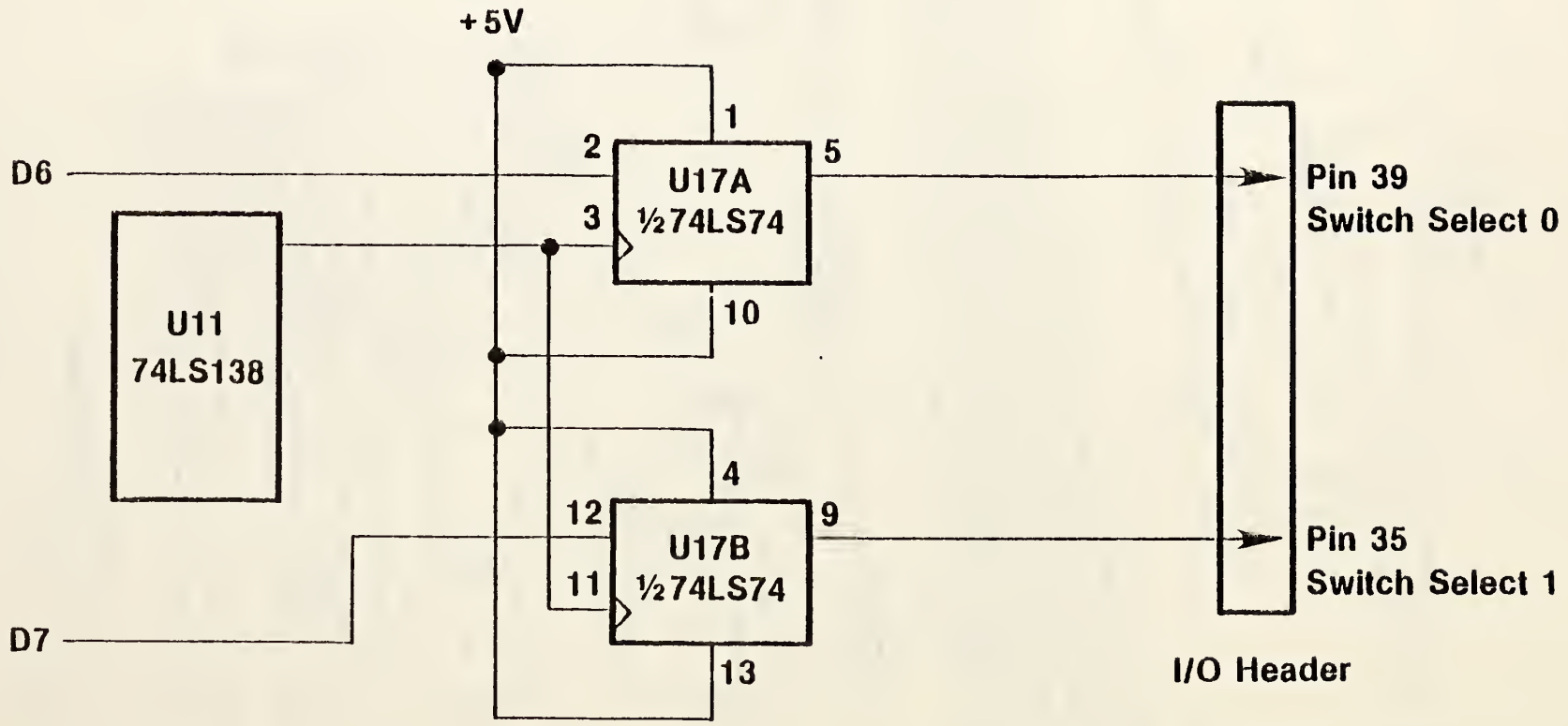


Figure 10

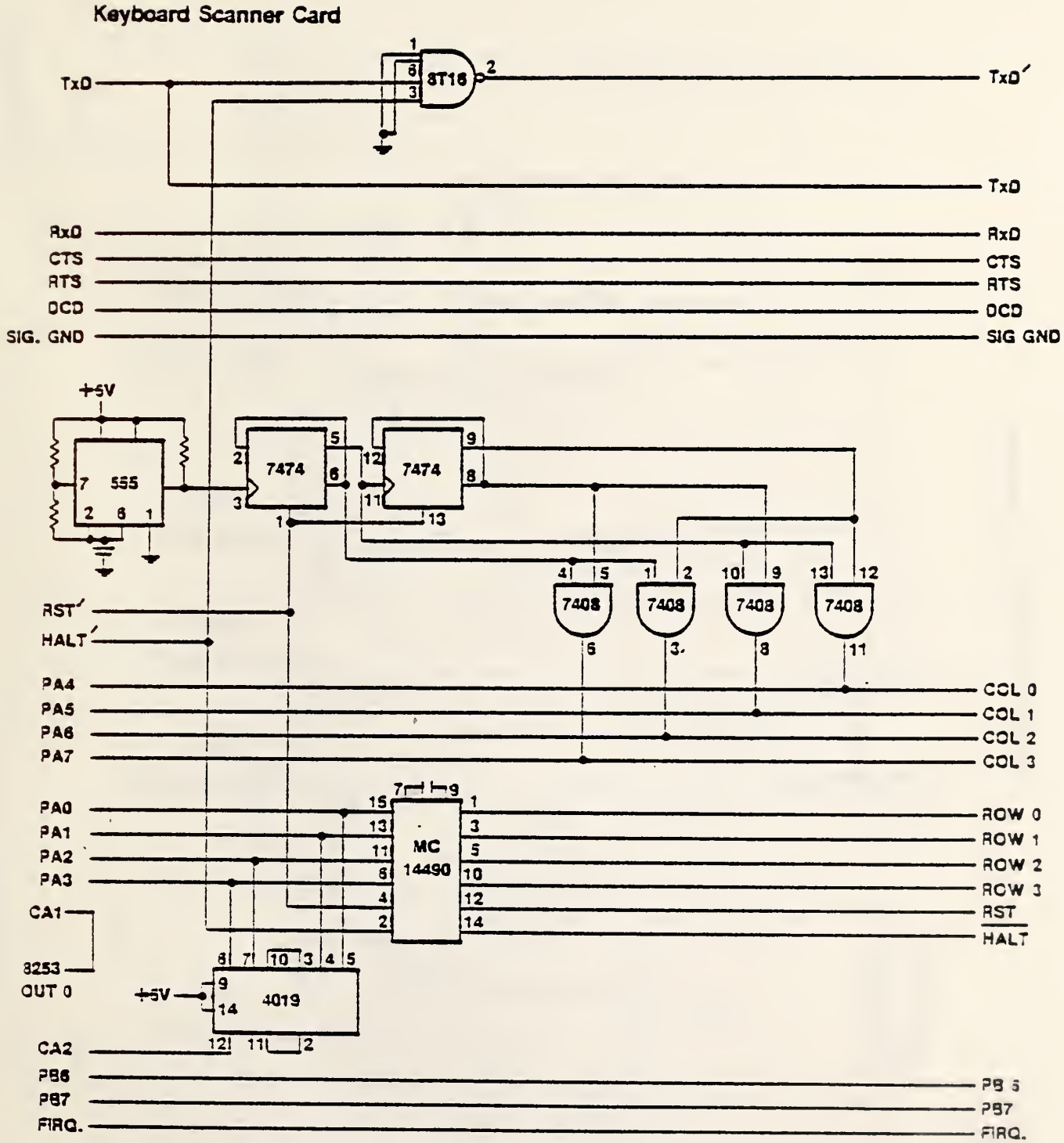

Keyboard Scanner Card
TxD
8T16
TxD'
TxD
RxD
CTS
RTS
DCD
SIG. GND
RxD
CTS
RTS
DCD
SIG GND
+5V
555
7474
7474
7408
7408
7408
7408
RST'
HALT'
PA4
PA5
PA6
PA7
COL 0
COL 1
COL 2
COL 3
PA0
PA1
PA2
PA3
MC
14490
ROW 0
ROW 1
ROW 2
ROW 3
RST
HALT
CA1
8253
OUT 0
+5V
4019
CA2
PB6
PB7
FIRQ.
PB 6
PB7
FIRQ.

Figure 11

Voltage to Current Converter

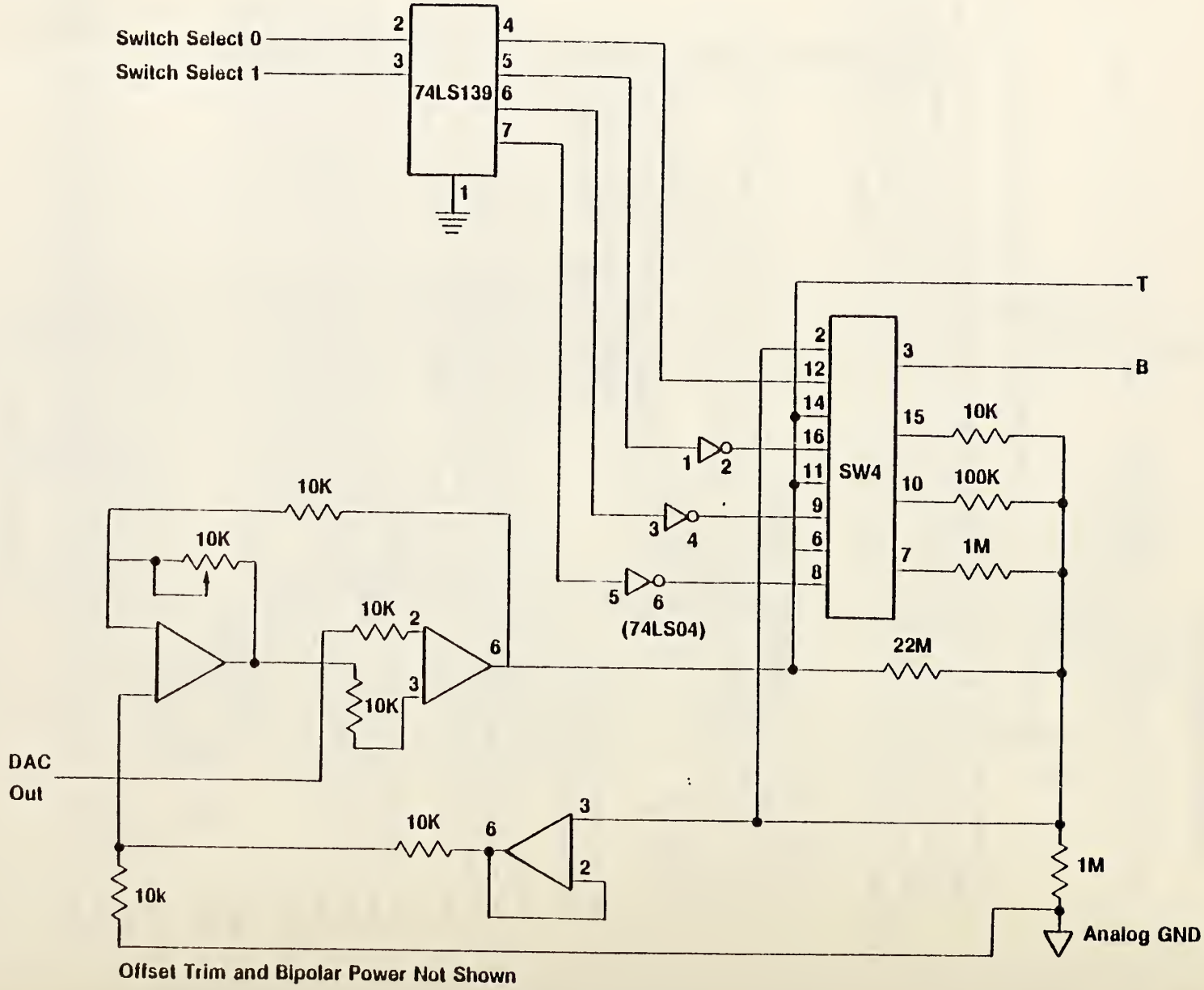


Figure 12

Input Card

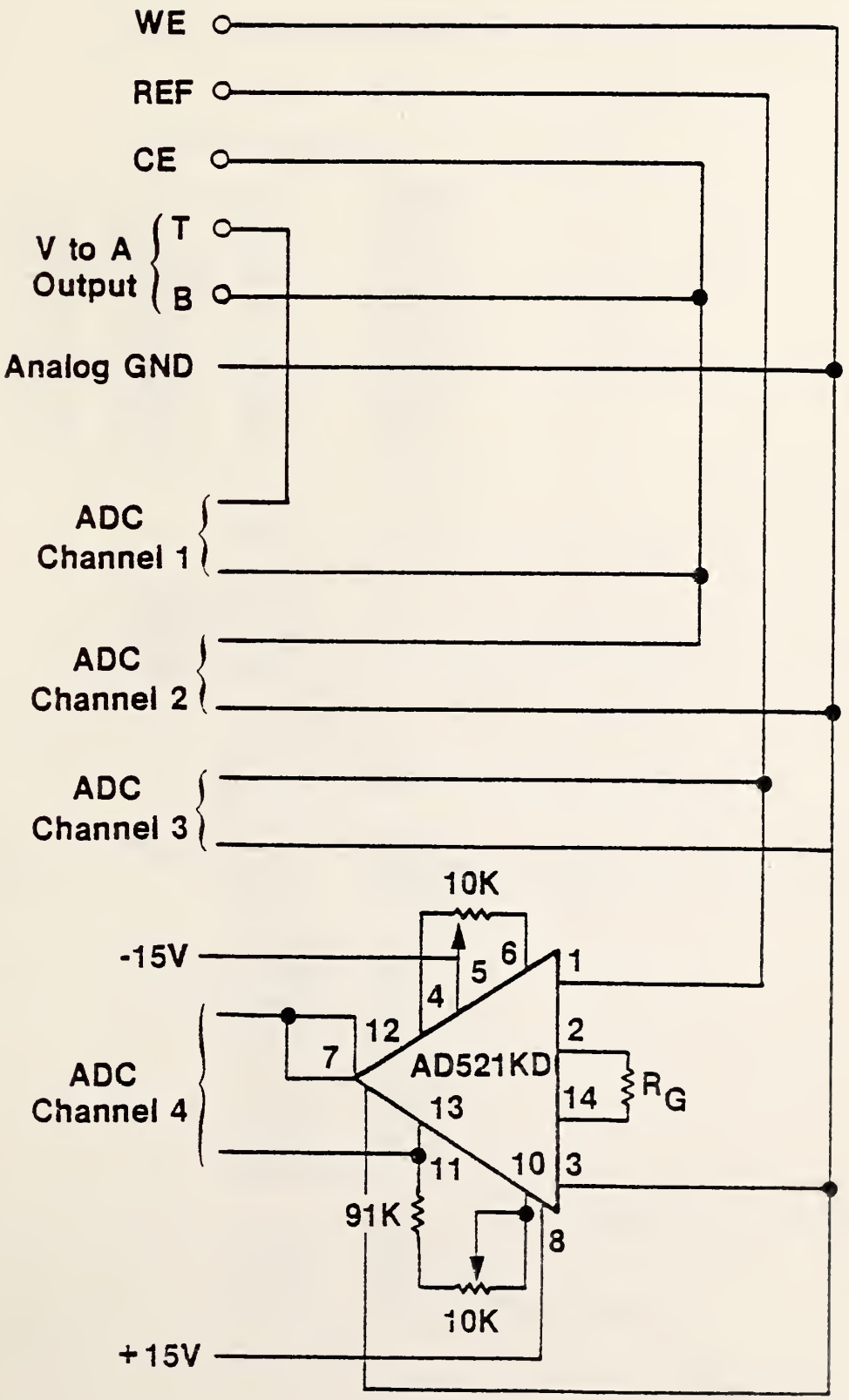


Figure 13

```
                    ************************************************

                    *                BEGIN

                    * THIS ROUTINE ISSUES PROMPTS AND STORES CONSTANT
                    * DATA FOR THE PORTABLE INSTRUMENT

                    ************************************************

                            OPT     EXP

                    * SYSTEM EQUATES

                0800  BUFFER  EQU     $0B00
                FECA  WFS     EQU     $FECA
                F9A3  GETDATA EQU     $F9A3
                0743  STARTD  EQU     $0743
                070B  DATBUF  EQU     $070B
                FB9C  PACKS   EQU     $FB9C
                FA83  CVDTB   EQU     $FA83
                0731  RUNFLG  EQU     $0731
                FB6A  GETR    EQU     $FB6A
                F194  MEASUR  EQU     $F194


0745                        ORG     $0745

0745                RUNSET  RMB     4
0749                TIMSET  RMB     4
074D                AREAST  RMB     4
0751                WORK    RMB     5

                0007        SETDP   $07

F000                        ORG     $F000

F000 0F   31      BEGIN   CLR     RUNFLG
F002 BE   0B00            LDX     #BUFFER     GET START OF BUFFER
F005 9F   0B              STX     DATBUF      SAVE IT

                    MSG     MACRO
                            LBSR    WFS
                            FCB     $0D,$0A
                            FCC     '&1'
                            FCB     $0
                            LDB     #$&2
                            LBSR    GETDATA
                            BEQ     &0
                            ENDM

F007                ID      MSG     "ID       (15 CHAR.-MAX) = ","10"
F007 17   0EC0              LBSR    WFS
F00A 0D 0A                  FCB     $0D,$0A
F00C 49 44 20 28            FCC     'ID (15 CHAR.-MAX) = '
F010 31 35 20 43
F014 48 41 52 2E
F018 2D 4D 41 58
F01C 29 20 3D 20
```

```
F020 00                         FCB     $0
F021 C6   10                    LDB     #$10
F023 17   097D                  LBSR    GETDATA
F026 27   DF                    BEQ     ID
                                ENDM
F028                    DATE    MSG     "DATE     (DDMMYR) = ",7
F028 17   0E9F                 LBSR    WFS
F02B 0D 0A                      FCB     $0D,$0A
F02D 44 41 54 45                FCC     'DATE (DDMMYR) = '
F031 20 28 44 44
F035 4D 4D 59 52
F039 29 20 3D 20
F03D 00                         FCB     $0
F03E C6   07                    LDB     #$7
F040 17   0960                  LBSR    GETDATA
F043 27   E3                    BEQ     DATE
                                ENDM
F045                    TIME    MSG     "TIME     TO NEXT MEASUREMENT (MMSS)= ",5
F045 17   0EB2                  LBSR    WFS
F048 0D 0A                      FCB     $0D,$0A
F04A 54 49 4D 45                FCC     'TIME TO NEXT MEASUREMENT (MMSS)= '
F04E 20 54 4F 20
F052 4E 45 58 54
F056 20 4D 45 41
F05A 53 55 52 45
F05E 4D 45 4E 54
F062 20 28 4D 4D
F066 53 53 29 3D
F06A 20
F06B 00                         FCB     $0
F06C C6   05                    LDB     #$5
F06E 17   0932                  LBSR    GETDATA
F071 27   D2                    BEQ     TIME
                                ENDM

F073 9E   0B                    LDX     DATBUF      POINT TO DATA
F075 34   20                    PSHS    Y           SAVE Y
F077 30   1B                    LEAX    -5,X        POINT TO MINUTES DATA
F079 17   00C0                  LBSR    CVTIM       GO CONVERT TO BINARY
F07C 86   3C                    LDA     #60         LOAD SEC/MIN
F07E 3D                         MUL                 MULTIPLY
F07F DD   49                    STD     TIMSET
F081 9E   0B                    LDX     DATBUF      POINT TO DATA, AGAIN
F083 30   1D                    LEAX    -3,X        POINT TO SECONDS
F085 17   00B4                  LBSR    CVTIM       CONVERT TO BINARY
F088 D3   49                    ADDD    TIMSET
F08A DD   49                    STD     TIMSET
F08C 35   20                    PULS    Y

F08E                    AREA    MSG     "AREA     OF SAMPLE (0-65535 CM↑2)= ",6
F08E 17   0E39                  LBSR    WFS
F091 0D 0A                      FCB     $0D,$0A
F093 41 52 45 41                FCC     'AREA OF SAMPLE (0-65535 CM↑2)= '
F097 20 4F 46 20
F09B 53 41 4D 50
F09F 4C 45 20 28
F0A3 30 2D 36 35
F0A7 35 33 35 20
F0AB 43 4D 5E 32
```

```
F0AF 29 3D 20
F0B2 00                         FCB     $0
F0B3 C6   06                    LDB     #$6
F0B5 17   08EB                  LBSR    GETDATA
F0B8 27   D4                    BEQ     AREA
                                ENDM
F0BA 9E   0B                    LDX     DATBUF      POINT TO INPUT DATA
F0BC 34   20                    PSHS    Y           SAVE Y
F0BE 8D   76                    BSR     INSAV
F0C0 DD   4D                    STD     AREAST      SAVE BINARY AREA
F0C2 35   20                    PULS    Y

F0C4                    RUNS    MSG     "RUNS       COUNT (100 OR LESS)= ",6
F0C4 17   0E03                  LBSR    WFS
F0C7 0D 0A                      FCB     $0D,$0A
F0C9 52 55 4E 53                FCC     'RUNS COUNT (100 OR LESS)= '
F0CD 20 43 4F 55
F0D1 4E 54 20 28
F0D5 31 30 30 20
F0D9 4F 52 20 4C
F0DD 45 53 53 29
F0E1 3D 20
F0E3 00                         FCB     $0
F0E4 C6   06                    LDB     #$6
F0E6 17   08BA                  LBSR    GETDATA
F0E9 27   D9                    BEQ     RUNS
                                ENDM
F0EB 9E   0B                    LDX     DATBUF      POINT TO DATA
F0ED 34   20                    PSHS    Y           SAVE Y
F0EF 8D   45                    BSR     INSAV
F0F1 DD   45                    STD     RUNSET      SAVE BINARY NUMBER OF RUNS
F0F3 35   20                    PULS    Y

F0F5 BE   0B00          CRT000  LDX     #BUFFER     POINT TO START OF INPUT DATA
F0F8 A6   80            CHARN   LDA     X+          GET CHAR
F0FA 81   0D                    CMPA    #$0D        IS IT A CR?
F0FC 27   5C                    BEQ     CG          IF SO, CHANGE IT
F0FE 9C   0B            CNTCM   CPX     DATBUF      HAVE WE REACHED END?
F100 26   F6                    BNE     CHARN       IF NOT, GET ANOTHER CHAR.
F102 8D   5B                    BSR     DATSAV
F104 CC   F194                  LDD     #MEASUR     POINT TO MEASUREMENT ROUTINE
F107 DD   31                    STD     RUNFLG
F109 17   0DBE                  LBSR    WFS
F10C 0D 0A                      FCB     $0D,$0A
F10E 50 52 45 53                FCC     'PRESS RUNWHEN READY FOR MEASUREMENT'
F112 53 20 52 55
F116 4E 20 57 48
F11A 45 4E 20 52
F11E 45 41 44 59
F122 20 46 4F 52
F126 20 4D 45 41
F12A 53 55 52 45
F12E 4D 45 4E 54
F132 00                         FCB     00
F133 16   0A34                  LBRA    GETR

F136 30   1A            INSAV   LEAX    -6,X
F138 17   0948                  LBSR    CVDTB       CONVERT TO BINARY
F13B 39                         RTS
```

```
F13C 108E 0751      CVTIM   LDY     #WORK
F140 C6   03                LDB     #$3
F142 86   30                LDA     #$30
F144 A7   A0        THIRTY  STA     Y+
F146 5A                     DECB
F147 26   FB                BNE     THIRTY
F149 C6   02                LDB     #$2
F14B A6   B0        SIXTY   LDA     X+          GET DATA
F14D A7   A0                STA     Y+          SAVE IT
F14F 5A                     DECB
F150 26   F9                BNE     SIXTY
F152 1F   21                TFR     Y,X
F154 30   1B                LEAX    -5,X
F156 17   092A              LBSR    CVDTB
F159 39                     RTS

F15A 4F             CG      CLRA
F15B A7   1F                STA     -1,X        REPLACE CR BY ZERO
F15D 20   9F                BRA     CNTCM


F15F 34   20        DATSAV  PSHS    Y           SAVE Y
F161 109E 43                LDY     STARTD      GET CMOS MEMEORY START
F164 8E   0800              LDX     #BUFFER     POINT TO DATA
F167 DC   0B                LDD     DATBUF
F169 83   0800              SUBD    #BUFFER
F16C 47                     ASRA                DIVIDE BY 4
F16D 56                     RORB
F16E 47                     ASRA
F16F 56                     RORB
F170 17   0A29              LBSR    PACKS
F173 109F 43                STY     STARTD      SAVE NEXT CMOS DATA ADDRESS
F176 9E   0B                LDX     DATBUF      POINT TO DATA INPUT AREA
F178 35   A0                PULS    Y,PC        RESTORE Y,RETURN

                            END
```

0 ERROR(S) DETECTED

SYMBOL TABLE:

```
AREA    F0BE    AREAST  074D    BEGIN   F000    BUFFER  0800    CG      F15A
CHARN   F0FB    CNTCM   F0FE    CRT000  F0F5    CVDTB   FA83    CVTIM   F13C
DATBUF  070B    DATE    F028    DATSAV  F15F    GETDAT  F9A3    GETR    FB6A
ID      F007    INSAV   F136    MEASUR  F194    PACKS   FB9C    RUNFLG  0731
RUNS    F0C4    RUNSET  0745    SIXTY   F14B    STARTD  0743    THIRTY  F144
TIME    F045    TIMSET  0749    WFS     FECA    WORK    0751
```

```
                ********************************************************

                *                       MEASUR

                * THIS ROUTINE HANDLES THE MEASUREMENT SEQUENCE IN
                * THE PORTABLE INSTRUMENT.  THE MEASURED DATA IS
                * STORED IN THE CMOS MEMORY AND THE ADDRESS UPDATED
                * FOR LATER RETRIEVAL IF DESIRED.

                ********************************************************

                * SYSTEM EQUATES

           0700 INDEX   EQU    $0700
           0702 ADCVAL  EQU    $0702
           0704 CHNUM   EQU    $0704
           0705 SWNUM   EQU    $0705
           0706 DACVAL  EQU    $0706
           070B DATBUF  EQU    $070B
           0733 RUNCNT  EQU    $0733
           0743 STARTD  EQU    $0743
           0745 RUNSET  EQU    $0745
           0749 TIMSET  EQU    $0749
           B004 SAVST1  EQU    $B004
           DE50 DDAC    EQU    $DE50

           0007         SETDP  $07

           F82F CGTIME  EQU    $F82F
           F839 TIMCHK  EQU    $F839
           F852 CHSELT  EQU    $F852
           F867 SMSELT  EQU    $F867
           F879 CONVRT  EQU    $F879
           F89D INITDA  EQU    $F89D
           F8B0 SWNSET  EQU    $F8B0
           F8BF SWNZER  EQU    $F8BF
           F8CB LDDAC   EQU    $F8CB
           FECA WFS     EQU    $FECA

0751                    ORG    $0751

0751       WORK     RMB    5
0756       REVFLG   RMB    1
0757       DACINI   RMB    2
0759       OPNCRK   RMB    2
075B       DACADJ   RMB    2

F194                    ORG    $F194

F194 17 0D38  MEASUR  LBSR   WFS          OUTPUT MESSAGE
F197 0D 0A            FCB    $0D,$0A
F199 57 4F 52 4B      FCC    'WORKING'
F19D 49 4E 47
F1A0 00               FCB    $00
F1A1 0F 33            CLR    RUNCNT
F1A3 CC 01FF          LDD    #$01FF       CORRESPONDS TO ZERO OUT
F1A6 DD 57            STD    DACINI       SAVE INITIAL VALUE
F1A8 CC 0033          LDD    #$0033       CORRESPONDS TO 1/2 MICROAMP
```

```
F1AB DD   5B              STD    DACADJ    SAVE ADJUSTMENT VALUE
F1AD 9E   43              LDX    STARTD    GET START OF CMOS MEMORY AREA
F1AF BF   8004            STX    SAVST1    SAVE START OF MEMORY AREA

F1B2 CC   000A    SELCH   LDD    #$000A
F1B5 ED   84              STD    X
F1B7 17   0675            LBSR   CGTIME    SET TIMER FOR 1 MSEC TIMEOUTS
F1BA B6   01              LDA    #$01      SET A TO D FOR CE TO WE, I-OFF
F1BC 97   04              STA    CHNUM
F1BE 17   0691            LBSR   CHSELT    SELECT CHANNEL
F1C1 17   06A8            LBSR   SMSELT    START SAMPLING MODE
F1C4 17   0672            LBSR   TIMCHK    WAIT FOR TIMEOUT
F1C7 17   06AF            LBSR   CONVRT    MEASURE
F1CA ED   81              STD    X++       SAVE VOLTAGE, I-OFF ZERO
F1CC 0C   04              INC    CHNUM
F1CE 17   0681            LBSR   CHSELT
F1D1 17   0693            LBSR   SMSELT
F1D4 17   06A2            LBSR   CONVRT    GET OPEN CIRCUIT POTENTIAL

F1D7 B6   00              LDA    #$00
F1D9 97   04              STA    CHNUM
F1DB 17   0674            LBSR   CHSELT    SET A TO D TO CURRENT CHANNEL
F1DE 17   0686            LBSR   SMSELT    SET TO SAMPLING MODE
F1E1 17   041C            LBSR   SETIO     GET ZERO CURRENT VALUES

F1E4 DC   5B      CURSET  LDD    DACADJ    GET ADJUSTMENT VALUE
F1E6 44                   LSRA             HALVE IT
F1E7 56                   RORB
F1E8 D3   57              ADDD   DACINI    ADD INITIAL VALUE
                  *       ****************************
                  *       ALTERNATE IS SUBTRACTION FOR
                  *          OTHER POLARITY
                  *       ****************************
F1EA DD   06              STD    DACVAL

F1EC 0C   33      NEXT    INC    RUNCNT
F1EE 9F   51              STX    WORK      SAVE INDEX
F1F0 17   0646            LBSR   TIMCHK    WAIT FOR TIMOUT
F1F3 17   06D5            LBSR   LDDAC     SET CURRENT
F1F6 17   06B7            LBSR   SWNSET    SET SWITCH
F1F9 17   0680            LBSR   TIMCHK    WAIT FOR ANOTHER TIMEOUT
F1FC 17   067A            LBSR   CONVRT    GET POTENTIAL DROP OVER RESISTOR
F1FF ED   81              STD    X++       SAVE R DROP
F201 0C   04              INC    CHNUM
F203 17   064C            LBSR   CHSELT
F206 17   065E            LBSR   SMSELT    SET TO READ CE TO WE POTENTIAL
F209 17   066D            LBSR   CONVRT    GET IT
F20C ED   81              STD    X++       SAVE CE TO WE, I-ON
F20E 0C   04              INC    CHNUM
F210 17   063F            LBSR   CHSELT
F213 17   0651            LBSR   SMSELT
F216 17   0620            LBSR   TIMCHK
F219 17   0447            LBSR   SWZERO    TURN OFF CURRENT
F21C 17   065A            LBSR   CONVRT    GET WE-REF, I-OFF
F21F ED   81              STD    X++       SAVE IT

F221 0A   04              DEC    CHNUM     POINT TO CE TO WE
F223 17   062C            LBSR   CHSELT
F226 17   0629            LBSR   CHSELT
```

```
F229 17   064D          LBSR   CONVRT    GET WE TO CE CURRENT OFF
F22C ED   B1            STD    X++       SAVE IT
F22E BF   B004          STX    SAVST1    SAVE NEXT DATA BLOCK ADDRESS

F231 0F   04            CLR    CHNUM
F233 17   061C          LBSR   CHSELT
F236 17   062E          LBSR   SMSELT    SELECT CURRENT READ,  AGAIN
F239 0D   56            TST    REVFLG    HAVE WE FOUND RANGE?
F23B 2B   06            BMI    RDONE     YES, THEN CALCULATE PARAMETERS
F23D 8D   3B            BSR    CALCI     DO CHECK FOR APPROPRIATE RANGES
F23F 9E   51            LDX    WORK      RESET INDEX
F241 20   A9            BRA    NEXT

F243 DC   45    RDONE   LDD    RUNSET    GET # OF RUNS TO BE PERFORMED
F245 1027 008D          LBEQ   CALCII    IF ZERO GO CALCULATE
F249 D0   33            SUBB   RUNCNT
F24B 102F 0087          LBLE   CALCII    IF DONE, DO FINAL CALCULATIONS
F24F 0F   4B            CLR    TIMSET+2
F251 0F   4C            CLR    TIMSET+3
F253 CC   2580          LDD    #$2580
F256 ED   84            STD    X         SET TIMEOUT FOR ONE SEC
F258 17   05D4          LBSR   CGTIME
F25B 17   05DB  TIMEOT  LBSR   TIMCHK
F25E DC   4B            LDD    TIMSET+2
F260 C3   0001          ADDD   #$0001
F263 DD   4B            STD    TIMSET+2
F265 1093 49            CMPD   TIMSET    ARE WE DONE?
F268 27   02            BEQ    TIMUP
F26A 20   EF            BRA    TIMEOT
F26C CC   000A  TIMUP   LDD    #$000A    SET FOR 1 MILLISEC TIMEOUT
F26F ED   84            STD    X
F271 17   05BB          LBSR   CGTIME

F274 BE   B004  MORE    LDX    SAVST1
F277 16   FF72          LBRA   NEXT

F27A                    ORG    $F27A

F27A            CALCI   RMB    23        RESERVE AREA FOR NEXT PROGRAM
F291            TWOS    RMB    69
F2D6            CALCII  RMB    2         ADDRESS OF CALCULATION PROGRAM

F600                    ORG    $F600

F600 B6   03    SETIO   LDA    #$03
F602 97   05            STA    SWNUM     POINT TO 5 MICROAMPERE FULL SCALE
F604 DC   57            LDD    DACINI    GET ZERO CURRENT EQUIVALENT
F606 DD   06            STD    DACVAL    SETUP TO OUTPUT IT

F608 DC   02    OPNSAV  LDD    ADCVAL    GET OPEN CIRCUIT VOLTAGE
F60A ED   81            STD    X++       SAVE IT IN CMOS MEMORY
F60C 17   FC82          LBSR   TWOS
F60F DD   59            STD    OPNCRK
F611 17   0225          LBSR   TIMCHK
F614 17   02B4          LBSR   LDDAC     SET FOR ZERO CURRENT
F617 17   0296          LBSR   SWNSET    TURN ON ZERO CURRENT
F61A 17   021C          LBSR   TIMCHK
F61D 0C   04            INC    CHNUM     POINT TO CE TO WE VOLTAGE
F61F 17   0230          LBSR   CHSELT
```

```
F622 17   0242          LBSR   SMSELT
F625 17   0251          LBSR   CONVRT    GET APPLIED VOLTAGE-I ON
F628 DC   02            LDD    ADCVAL    RETRIEVE CE TO WE POTENTIAL
F62A ED   81            STD    X++       SAVE IT
F62C 86   00            LDA    #$00
F62E 97   04            STA    CHNUM     POINT TO CURRENT CHANNEL AGAIN
F630 17   021F          LBSR   CHSELT
F633 17   0231          LBSR   SMSELT
F636 17   0200          LBSR   TIMCHK
F639 17   023D          LBSR   CONVRT    GET DROP ACROSS R
F63C 17   0228          LBSR   SMSELT
F63F 17   027D          LBSR   SWNZER    TURN OFF ZERO CURRENT
F642 DC   02            LDD    ADCVAL    RETRIEVE DROP ACROSS R
F644 ED   81            STD    X++       SAVE IT
F646 39                 RTS

F647 DD   06    SETI01  STD    DACVAL    SAVE ZERO CURRENT VALUE
F649 17   027F          LBSR   LDDAC     SET CURRENT TO NEW ZERO
F64C 17   0261          LBSR   SWNSET    TURN ON CURRENT
F64F 17   01E7          LBSR   TIMCHK
F652 17   0224          LBSR   CONVRT    GET NEW CURRENT ZERO
F655 17   0267          LBSR   SWNZER    TURN OFF SWITCH
F658 DC   02            LDD    ADCVAL    RETRIEVE VALUE
F65A ED   14            STD    -12,X     SAVE IT IN ZERO LOCATION
F65C 17   020B          LBSR   SMSELT
F65F 39                 RTS

F660 17   023A    SWBEGN  LBSR   INITDA    INITIALIZE DAC
F663 9F   00      SWZERO  STX    INDEX     SAVE INDEX
F665 BE   DE50            LDX    #DDAC     SET OUTPUT TO ZERO ROUTINE
F668 CC   8000            LDD    #$8000
F66B ED   84              STD    X
F66D E7   05              STB    5,X       TURN OFF SWITCH
F66F 9E   00              LDX    INDEX     RESTORE INDEX
F671 39                   RTS

F672                END

0 ERROR(S) DETECTED

SYMBOL TABLE:

ADCVAL 0702   CALCI  F27A   CALCII F2D6   CGTIME F82F   CHNUM  0704
CHSELT F852   CONVRT F879   CURSET F1E4   DACADJ 075B   DACINI 0757
DACVAL 0706   DATBUF 070B   DDAC   DE50   END    F672   INDEX  0700
INITDA F89D   LDDAC  F8C8   MEASUR F194   MORE   F274   NEXT   F1EC
OPNCRK 0759   OPNSAV F608   RDONE  F248   REVFLG 0756   RUNCNT 0733
RUNSET 0745   SAVST1 8004   SELCH  F1B2   SETIO  F600   SETI01 F647
SMSELT F867   STARTD 0748   SWBEGN F660   SWNSET F8B0   SWNUM  0705
SWNZER F8BF   SWZERO F663   TIMCHK F839   TIMEOT F25B   TIMSET 0749
TIMUP  F26C   TWOS   F291   WFS    FECA   WORK   0751
```

```
                        ********************************************************

                        *                    CALCI

                        * THIS ROUTINE DOES CALCULATIONS FOR THE ADJUST-
                        * MENT OF THE CURRENT TO RESULT IN A FIXED REF TO
                        * WORKING ELECTRODE POTENTIAL


                        ********************************************************

                        * SYSTEM EQUATES

                   0759 OPNCRK  EQU     $0759
                   0733 RUNCNT  EQU     $0733
                   075B DACADJ  EQU     $075B
                   0706 DACVAL  EQU     $0706
                   0705 SWNUM   EQU     $0705
                   0756 REVFLG  EQU     $0756
                   0757 DACINI  EQU     $0757
                   FECA WFS     EQU     $FECA
                   0731 RUNFLG  EQU     $0731
                   FB68 GETR    EQU     $FB68
                   FC00 STARTCL EQU     $FC00      COLD START ON ERROR
                   F647 SETIO1  EQU     $F647

F27A                            ORG     $F27A

                   0007         SETDP   $07

F27A 0A   33       CALCI   DEC     RUNCNT     REDUCE RUN COUNT TO REFLECT
                           *                  DATA NOT YET FOUND
F27C EC   1E               LDD     -2,X       GET REF TO WE POTENTIAL
F27E A3   12               SUBD    -14,X      GET DIFFERENCE FROM OPEN CIRCUIT
F280 2B   19               BMI     POLAR
F282 B4   0F       TEST1   ANDA    #$0F       CLEAR UPPER 4 BITS
F284 1083 000A             CMPD    #$000A     IS THE DIFFERENCE 10 MV?
F288 2D   1B               BLT     ADJUST
F28A 96   56               LDA     REVFLG
F28C 8A   F0               ORA     #$F0       SET FLAG TO INDICATE CURRENT FOUND

F28E 97   56               STA     REVFLG
F290 39            RETURN  RTS

F291 85   08       TWOS    BITA    #$08
F293 27   03               BEQ     PLUS
F295 8A   F8               ORA     #$F8       BIT 3--SET,SIGN EXTEND,ALL ONES
F297 39                    RTS
F298 B4   07       PLUS    ANDA    #$07       IF BIT 3 IS ZERO
F29A 39                    RTS                SIGN EXTEND ALL ZEROS, AND RETURN

F29B 8D   02       POLAR   BSR     NEGD       GET TWO'S COMPLEMENT OF D
F29D 20   E3               BRA     TEST1

F29F 43            NEGD    COMA
F2A0 53                    COMB
F2A1 C3   0001             ADDD    #$01
F2A4 39                    RTS
```

```
F2A5 DC   06       ADJUST  LDD    DACVAL    GET OLD CURRENT SET
F2A7 D3   5B               ADDD   DACADJ
F2A9 1083 03FF             CMPD   #$3FF     HAVE WE REACHED FULL SCALE?
F2AD 2C   03               BGE    RANGE
F2AF DD   06       CHANGE  STD    DACVAL
F2B1 39                    RTS

F2B2 DC   57       RANGE   LDD    DACINI    GET INITIAL VALUE
F2B4 0A   05               DEC    SWNUM
F2B6 27   03               BEQ    ERROR3
F2B8 16   03BC             LBRA   SETI01

F2BB 17   0C0C     ERROR3  LBSR   WFS
F2BE 0D 0A                 FCB    $0D,$0A
F2C0 4F 55 54 20           FCC    'OUT OF RANGE'
F2C4 4F 46 20 52
F2C8 41 4E 47 45
F2CC 00                    FCB    $00
F2CD CC   FC00             LDD    #STARTCL
F2D0 DD   31               STD    RUNFLG
F2D2 17   0893             LBSR   GETR

F2D6                       ORG    $F2D6

F2D6               CALCII  RMB    2         ADDRESS OF NEXT ROUTINE

                           END

0 ERROR(S) DETECTED

SYMBOL TABLE:

ADJUST F2A5   CALCI  F27A   CALCII F2D6   CHANGE F2AF   DACADJ 075B
DACINI 0757   DACVAL 0706   ERROR3 F2BB   GETR   FB6B   NEGD   F29F
OPNCRK 0759   PLUS   F298   POLAR  F29B   RANGE  F2B2   RETURN F290
REVFLG 0756   RUNCNT 0733   RUNFLG 0731   SETI01 F647   STARTC FC00
SWNUM  0705   TEST1  F282   TWOS   F291   WFS    FECA
```

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                ********************************************************

                *                       CALCII

                * THIS ROUTINE DOES FINAL CALCULATIONS PRIOR TO THE
                * OUTPUT OF DATA. RESULTS ARE CALCULATED AND FORMAT
                * DETERMINED.
                * ALGORITHMS ARE:  R'=(CE TO WE)/V(ACROSS RESISTOR)
                *                                TIMES R

                * OHMS X CM↑2 = KV(REF TO WE)-V(OPEN CIRCUIT)/I XAREA

                *                   K IS CONVERSION FACTOR TO VOLTS/AMPS


                ************************************************************


                * SYSTEM EQUATES

0700   INDEX    EQU     $0700
0705   SWNUM    EQU     $0705
070B   DATBUF   EQU     $070B
074D   AREAST   EQU     $074D
0751   WORK     EQU     $0751
0759   OPNCRK   EQU     $0759
0743   STARTD   EQU     $0743
B002   SAVST0   EQU     $B002
B004   SAVST1   EQU     $B004

F29F   NEGD     EQU     $F29F
F7C0   MUL16    EQU     $F7C0
FAB1   CVBTD    EQU     $FAB1
F77E   DIV16    EQU     $F77E
FB6B   GETR     EQU     $FB6B
FECA   WFS      EQU     $FECA

075D                    ORG     $075D

075D           APVIOF   RMB     2
075F           POTENT   RMB     2
0761           APVION   RMB     2
0763           IRSW     RMB     2
0765           RONEA    RMB     2
0767           RONEC    RMB     1
0768           EXPON    RMB     1
0769           KONEA    RMB     2
076B           KTHREE   RMB     1
076C           RDAT0    RMB     1
076D           RDAT1    RMB     9
0776           KDAT0    RMB     1
0777           KDAT1    RMB     8
077F           KDAT6    RMB     2
0781           TEN      RMB     2

0790                    ORG     $0790

0790           PRESTR   RMB     6
```

```
0796                    WSTORE  RMB     5
079B                    CNT     RMB     1

                0007            SETDP   $07

F2D6                            ORG     $F2D6

F2D6 CC   000A      CALCII  LDD     #$0A
F2D9 DD   B1                    STD     TEN         SET SHIFT MULTIPLIER
F2DB 34   20                    PSHS    Y           SAVE Y
F2DD 109E 43                    LDY     STARTD      POINT TO ZERO DATA
F2E0 EC   B3                    LDD     --X         GET MEASURED VALUE I-OFF
F2E2 A3   A1                    SUBD    Y++         SUBTRACT ZERO VALUE
F2E4 2A   02                    BPL     STORE1
F2E6 8D   B7                    BSR     NEGD        IF NEGATIVE, COMPLEMENT
F2E8 DD   5D        STORE1  STD     APVIOF
F2EA EC   B3                    LDD     --X         GET OPEN CIRCUIT VALUE
F2EC A3   A1                    SUBD    Y++         SUBTRACT MEASURED VALUE
F2EE 2A   02                    BPL     STORE2
F2F0 8D   AD                    BSR     NEGD
F2F2 DD   5F        STORE2  STD     POTENT      SAVE IT
F2F4 27   7D                    BEQ     ERROR5
F2F6 EC   B3                    LDD     --X         GET GET APPLIED VOLTAGE,I-ON
F2F8 A3   A1                    SUBD    Y++         SUBTRACT CE TO WE, I-OFF
F2FA 2A   02                    BPL     STORE3
F2FC 8D   A1                    BSR     NEGD
F2FE DD   61        STORE3  STD     APVION
F300 27   71                    BEQ     ERROR5
F302 EC   B3                    LDD     --X         GET DROP ACROSS RESISTOR
F304 A3   A1                    SUBD    Y++         SUBTRACT ZERO CURRENT VALUE
F306 2A   02                    BPL     STORE4
F308 8D   95                    BSR     NEGD
F30A DD   63        STORE4  STD     IRSW
F30C 27   65                    BEQ     ERROR5
F30E 35   20                    PULS    Y

F310 9F   0B        RAPPAR  STX     DATBUF      SAVE INDEX
F312 0F   9B                    CLR     CNT
F314 0F   68                    CLR     EXPON
F316 34   20                    PSHS    Y           SAVE Y
F318 8E   0763                  LDX     #IRSW
F31B 108E 0761                  LDY     #APVION     POINT TO VOLTAGE(CE TO WE)
F31F 17   025E                  LBSR    SHIFT
F322 DD   65                    STD     RONEA       SAVE BINARY RESULT
F324 8E   076D                  LDX     #RDAT1      POINT TO ASCII STORAGE AREA
F327 17   0787                  LBSR    CVBTD       MAKE ASCII DATA AND STORE
F32A 35   20                    PULS    Y

F32C 8E   F3AC      CVR     LDX     #RTBL       POINT TO TABLE OF RESISTANCES
F32F D6   05                    LDB     SWNUM       GET WORKING SWITCH NUMBER
F331 3A                         ABX                 POINT TO VALUE
F332 A6   84                    LDA     X
F334 27   56                    BEQ     ERROR6
F336 97   67                    STA     RONEC       SAVE RESISTANCE
F338 8E   076D                  LDX     #RDAT1
F33B 17   00F6                  LBSR    DECIMP      GO SET UP ASCII OUTPUT DATA
>F33E 16  006F                  LBRA    CORRK

F341 35   20        ERROR4  PULS    Y
```

```
F343 17   0B84            LBSR   WFS
F346 0D 0A                FCB    $0D,$0A
F348 44 41 54 41          FCC    'DATA EXCEED ALLOWABLE POTENTIAL LIMITS!'
F34C 20 45 58 43
F350 45 45 44 20
F354 41 4C 4C 4F
F358 57 41 42 4C
F35C 45 20 50 4F
F360 54 45 4E 54
F364 49 41 4C 20
F368 4C 49 4D 49
F36C 54 53 21
F36F 00                   FCB    $00
F370 16   07F5            LBRA   GETR

F373 17   0B54    ERROR5  LBSR   WFS
F376 0D 0A                FCB    $0D,$0A
F378 44 41 54 41          FCC    'DATA READS ZERO!'
F37C 20 52 45 41
F380 44 53 20 5A
F384 45 52 4F 21
F388 00                   FCB    $00
F389 16   07DC            LBRA   GETR

F38C 17   0B3B    ERROR6  LBSR   WFS
F38F 0D 0A                FCB    $0D,$0A
F391 53 57 49 54          FCC    'SWITCH WAS SET TO ZERO!'
F395 43 48 20 57
F399 41 53 20 53
F39D 45 54 20 54
F3A1 4F 20 5A 45
F3A5 52 4F 21
F3A8 00                   FCB    $00
F3A9 16   07BC            LBRA   GETR

F3AC 00           RTBL    FCB    $00        VALUES CORRESPONDING TO SWITCH
F3AD 04 05 06             FCB    $04,$05,$06 THESE ARE EXPONENTS

                  ************************************************
                  *     FOR EPRI INSTRUMENT USE $02,$03,$04
                  ************************************************

F3B0 B6   00      CORRK   LDA    #$00       SET CONSTANT FOR CONVERSION
F3B2 97   68              STA    EXPON
F3B4 97   9B              STA    CNT
F3B6 34   20              PSHS   Y
F3B8 108E 075F            LDY    #POTENT
F3BC DC   5F              LDD    POTENT     GET VALUE OF REF TO WE
F3BE 1083 0041            CMPD   #$0041
F3C2 102E FF7B            LBGT   ERROR4     GREATER THAN 65 MILLIVOLTS, ERROR
F3C6 8E   0763            LDX    #IRSW      POINT TO POTENTIAL ACROSS RESISTOR

F3C9 0C   9B              INC    CNT        SET TO MULTIPLY ANSWER BY TWO
F3CB 17   01B2            LBSR   SHIFT
F3CE 0A   68              DEC    EXPON      DIVIDE ANSWER BY TEN
F3D0 DD   69              STD    KONEA
F3D2 35   20              PULS   Y
F3D4 34   70              PSHS   X,Y,U
F3D6 8D   10              BSR    MLAREA     TIMES AREA - STORE ASCII DATA
```

```
F3DB 35   70              PULS   X,Y,U      RESTORE REGISTERS
F3DA BE   8002            LDX    SAVST0
F3DD 9F   00              STX    INDEX
F3DF BE   8004            LDX    SAVST1     GET FINAL ADDRESS OF DATA
F3E2 BF   8002            STX    SAVST0     START FOR SAVE CMOS MEMORY
F3E5 16   0082            LBRA   PUTDAT

F3E8 BE   0769    MLAREA  LDX    #KONEA     POINT TO V/A DATA
F3EB 108E 074D            LDY    #AREAST    POINT TO AREA DATA
F3EF EC   A4              LDD    Y          GET AREA
F3F1 26   05              BNE    MLD        IF NON-ZERO GO
F3F3 CC   0001            LDD    #$0001     IF AREA ZERO DEFAULT
F3F6 ED   A4              STD    Y          TO 1
F3F8 CE   0751    MLD     LDU    #WORK      POINT TO RESULT STORAGE LOCATION
F3FB 17   03C2            LBSR   MUL16

                  ********************************************

                  * THE NEXT ROUTINE ROUNDS OFF DATA TO 16 BIT

                  ********************************************

F3FE EC   C4      MLCHAR  LDD    U          FETCH STORED RESULT
F400 27   09              BEQ    CNTMC      IF NON-ZERO - ROUNDOFF NEEDED
F402 8D   16              BSR    ROUNDF
F404 EC   42              LDD    2,U        GET DATA
F406 17   01AF            LBSR   SHIFTB     FINISH ROUNDOFF PROCEDURE
F409 ED   42              STD    2,U        SAVE RESULT
F40B EC   42      CNTMC   LDD    2,U        GET ROUNDED DATA
F40D DD   69              STD    KONEA
F40F 8E   0777            LDX    #KDAT1     POINT TO ASCII STORAGE AREA
F412 17   069C            LBSR   CVBTD      MAKE ASCII AND STORE
F415 8E   0777            LDX    #KDAT1
F418 20   1A              BRA    DECIMP

F41A 84   FF      ROUNDF  ANDA   #$FF       BYTE ZERO?
F41C 27   09              BEQ    BYTE2
F41E 44                   LSRA              SHIFT D RIGHT
F41F 56                   RORB
F420 17   01A0            LBSR   UPDATE     ELSE ADJUST LOWER HALF
F423 0C   9B              INC    CNT
F425 20   F3      LOOPR   BRA    ROUNDF     DO NEXT BIT

F427 C4   FF      BYTE2   ANDB   #$FF       IS BYTE ZERO?
F429 27   08              BEQ    ENDRND     GO, DONE
F42B 54                   LSRB              ELSE SHIFT NEXT BIT
F42C 17   0194            LBSR   UPDATE
F42F 0C   9B              INC    CNT
F431 20   F4      LOOPB   BRA    BYTE2
F433 39           ENDRND  RTS

F434 96   67      DECIMP  LDA    RONEC      GET RESISTANCE EXPONENT
F436 9B   68              ADDA   EXPON      ADJUST EXPONENT
F438 8B   04              ADDA   #$04       POSITION ADJUST FOR DECIMAL POINT
F43A 97   68              STA    EXPON      SAVE IT
F43C 81   0A              CMPA   #$0A       IS EXPONENT 10
F43E 27   0F              BEQ    TENEXP
F440 80   0A              SUBA   #$0A       IS EXPONENT >10
F442 2B   06              BMI    SINGEX
```

```
F444 1F   89              TFR    A,B        SAVE ONES DIGIT
F446 86   01              LDA    #$01       SET TENS
F448 20   08              BRA    DECDAT
F44A 4F           SINGEX  CLRA               SET TENS TO ZERO
F44B D6   68              LDB    EXPON      GET ONES DIGIT
F44D 20   03              BRA    DECDAT
F44F 5F           TENEXP  CLRB               SET ONES DIGIT TO ZERO
F450 86   01              LDA    #$01       SET TENS TO ONE

F452 8A   30      DECDAT  ORA    #$30
F454 CA   30              ORB    #$30       MAKE EXPONENT ASCII
F456 E7   07              STB    7,X
F458 A7   06              STA    6,X
F45A A6   84              LDA    X
F45C A7   1F              STA    -1,X
F45E 86   2E              LDA    #'.        PUT DECIMAL POINT IN DATA
F460 A7   84              STA    X
F462 86   45              LDA    #'E        PUT EXPONENTIAL SIGN IN DATA
F464 A7   05              STA    5,X
F466 39                   RTS

F46A                      ORG    $F46A


F46A              PUTDAT  RMB    2          STARTING ADDRESS OUTPUT DATA


F580                      ORG    $F580

F580 EC   A4      SHIFT   LDD    0,Y        GET MULTIPLICAND
F582 DD   90              STD    PRESTR
F584 34   20              PSHS   Y          SAVE Y POINTER
F586 10BE 0790            LDY    #PRESTR
F58A 9F   00              STX    INDEX      SAVE POINTER
F58C 8E   0781    SHIFT1  LDX    #TEN       POINT TO MULTIPLIER
F58F CE   0751            LDU    #WORK      POINT TO STORAGE
F592 17   022B            LBSR   MUL16      GO MULTIPLY
F595 0A   68              DEC    EXPON      ADJUST EXPONENT
F597 DC   51              LDD    WORK       GET UPPER 16 BITS
F599 26   06              BNE    USERND     IF NOT ZERO, ROUND OFF
F59B DC   53              LDD    WORK+2     GET DATA
F59D ED   A4              STD    0,Y
F59F 20   EB              BRA    SHIFT1     IF ZERO, DO AGAIN
F5A1 17   FE76    USERND  LBSR   ROUNDF     ROUND OFF
F5A4 35   20              PULS   Y
F5A6 DC   53      USEABL  LDD    WORK+2     GET USABLE PART OF DATA
F5A8 27   22              BEQ    ERROR7
F5AA ED   A4              STD    0,Y        SAVE VALUE
F5AC 9E   00              LDX    INDEX      RESTORE POINTER

F5AE 34   40      PROCES  PSHS   U          SAVE U REGISTER
F5B0 CE   0796            LDU    #WSTORE    POINT TO SCRATCH AREA
F5B3 17   01C8            LBSR   DIV16
F5B6 35   40              PULS   U
F5B8 0D   9B      SHIFTB  TST    CNT        TEST ADJUSTMENT COUNT
F5BA 27   06              BEQ    ENDPRO     IF ZERO NONE NECESSARY
F5BC 58                   ASLB              ELSE MULTIPLY ANSWER BY 2
F5BD 49                   ROLA
F5BE 0A   9B              DEC    CNT
```

```
F5C0 20   F6              BRA     SHIFTB
F5C2 39           ENDPRO  RTS             RETURN

F5C3 06   53      UPDATE  ROR     WORK+2  SHIFT LOWER WORD
F5C5 06   54              ROR     WORK+3
F5C7 24   02              BCC     BACK
F5C9 0C   54              INC     WORK+3  IF BIT WAS SET ADJUST LAST BIT
F5CB 39           BACK    RTS

F5CC 35   20      ERROR7  PULS    Y
F5CE 16   FDA2            LBRA    ERROR5

                          END

0 ERROR(S) DETECTED

SYMBOL TABLE:

APVIOF 075D   APVION 0761   AREAST 074D   BACK   F5CB   BYTE2  F427
CALCII F2D6   CNT    079B   CNTMC  F40B   CORRK  F3B0   CVBTD  FAB1
CVR    F32C   DATBUF 070B   DECDAT F452   DECIMP F434   DIV16  F77E
ENDPRO F5C2   ENDRND F433   ERROR4 F341   ERROR5 F373   ERROR6 F38C
ERROR7 F5CC   EXPON  0768   GETR   FB6B   INDEX  0700   IRSW   0763
KDAT0  0776   KDAT1  0777   KDAT6  077F   KONEA  0769   KTHREE 076B
LOOP9  F431   LOOPR  F425   MLAREA F3EB   MLCHAR F3FE   MLD    F3F8
MUL16  F7C0   NEGD   F29F   OPNCRK 0759   POTENT 075F   PRESTR 0790
PROCES F5AE   PUTDAT F46A   RAPPAR F310   RDAT0  076C   RDAT1  076D
RONEA  0765   RONEC  0767   ROUNDF F41A   RTBL   F3AC   SAVST0 8002
SAVST1 8004   SHIFT  F580   SHIFT1 F58C   SHIFTB F5B8   SINGEX F44A
STARTD 0743   STORE1 F2EB   STORE2 F2F2   STORE3 F2FE   STORE4 F30A
SWNUM  0705   TEN    0781   TENEXP F44F   UPDATE F5C3   USEABL F5A6
USERND F5A1   WFS    FECA   WORK   0751   WSTORE 0796
```

```
                ****************************************************

                *                  PUTDATA

                * THIS ROUTINE OUTPUTS THE FINAL RESULTS TO THE
                * DISPLAY.  IT THEN PROMPTS FOR CMOS MEMORY SAVE,
                * AND THEN FOR CONTINUATION.  IF NOTHING FURTHER
                * IS DESIRED, IT GOES INTO AN ENDLESS WAIT LOOP
                * UNTIL POWER DOWN.


                ****************************************************

                * SYSTEM EQUATES

           0700 INDEX   EQU    $0700
           0800 BUFFER  EQU    $0800
           076C RDAT0   EQU    $076C
           0776 KDAT0   EQU    $0776
           DE20 ACIA    EQU    $DE20
           0756 REVFLG  EQU    $0756
           070B DATBUF  EQU    $070B
           0743 STARTD  EQU    $0743

           DE28 KEYPAD  EQU    $DE28
           F949 KBINCH  EQU    $F949
           FC00 STARTCL EQU    $FC00
           FB7D PGMSAV  EQU    $FB7D
           FBCC UNPAKS  EQU    $FBCC
           FECA WFS     EQU    $FECA
           FF08 WRC     EQU    $FF08
           F2D6 CALCII  EQU    $F2D6

           0007         SETDP  $07

F46A                    ORG    $F46A

F46A 0D  56    PUTDAT   TST    REVFLG    IS THIS FIRST OUTPUT POINT?
F46C 26  02             BNE    HEADER    IF SET, OUTPUT HEADER
F46E 20  22             BRA    ROUT      ELSE OUTPUT NEXT DATA POINT

F470 0F  56    HEADER   CLR    REVFLG
F472 17  00C5           LBSR   CRLF
F475 8E  0800           LDX    #BUFFER   POINT TO HEADER DATA

F478 C6  0F             LDB    #15       OUTPUT ID
F47A 108E DE20          LDY    #ACIA
F47E 17  00C4           LBSR   OUTDAT
F481 A6  80             LDA    X+        INCREMENT X, CHECK FOR LAST CHAR.
F483 1026 00DB          LBNE   ERROR7

F487 17  00C4  OUTSS    LBSR   OUT4S
F48A C6  06             LDB    #6
F48C 17  00B6           LBSR   OUTDAT    OUTPUT DATE
F48F 17  009C           LBSR   CHARIN    WAIT FOR CHARACTER
```

```
F492 17   00A5      ROUT    LBSR    CRLF
F495 17   0A32              LBSR    WFS
F498 52 27 20 3D            FCC     "R' = ",$00
F49C 20 00
F49E 8E   076C              LDX     #RDAT0      POINT TO R'DATA
F4A1 C6   09                LDB     #9
F4A3 17   009F              LBSR    OUTDAT      OUTPUT R'
F4A6 17   0A21              LBSR    WFS
F4A9 20 4F 48 4D            FCC     ' OHMS',$00
F4AD 53 00
F4AF 8D   7D                BSR     CHARIN      WAIT FOR CHARACTER

F4B1 17   0086      KOUT    LBSR    CRLF
F4B4 17   0A13              LBSR    WFS
F4B7 4B 20 3D 20            FCC     'K = ',$00
F4BB 00
F4BC 8E   0776              LDX     #KDAT0
F4BF C6   09                LDB     #9
F4C1 17   0081              LBSR    OUTDAT      OUTPUT K
F4C4 17   0A03              LBSR    WFS
F4C7 20 4F 48 4D            FCC     ' OHM X CM↑2  ',$00
F4CB 20 58 20 43
F4CF 4D 5E 32 20
F4D3 20 00
F4D5 8D   57                BSR     CHARIN      WAIT FOR CHARACTER
F4D7 9E   43                LDX     STARTD      GET BEGINNING OF FILE
F4D9 30   08                LEAX    8,X         OFFSET BY ZERO LOCATIONS
F4DB 9C   0B                CPX     DATBUF      HAVE WE REACHED END OF DATA
F4DD 27   05                BEQ     EXIT
F4DF 9E   0B                LDX     DATBUF      ELSE, LOAD POINTER TO NEXT DATA
F4E1 16   FDF2              LBRA    CALCII      GO DO IT

F4E4 8D   54        EXIT    BSR     CRLF
F4E6 17   09E1              LBSR    WFS
F4E9 53 41 56 45            FCC     'SAVE DATA?   YES = 1',$00
F4ED 20 44 41 54
F4F1 41 3F 20 20
F4F5 20 59 45 53
F4F9 20 3D 20 31
F4FD 00
F4FE 8D   2E                BSR     CHARIN
F500 C1   31                CMPB    #$31        IS IT A ONE?
F502 27   31                BEQ     DSAVE
F504 8D   34        ANOTHR  BSR     CRLF
F506 17   09C1              LBSR    WFS
F509 57 41 4E 54            FCC     'WANT ANOTHER RUN?  YES = 1',$00
F50D 20 41 4E 4F
F511 54 48 45 52
F515 20 52 55 4E
F519 3F 20 20 59
F51D 45 53 20 3D
F521 20 31 00

F524 8D   0B                BSR     CHARIN
F526 C1   31                CMPB    #$31
F528 1027 06D4              LBEQ    STARTCL
F52C 20   FE                BRA     *           THIS IS AN ENDLESS LOOP!
```

```
F52E B6   DE2B      CHARIN  LDA     KEYPAD     CLEAR KEYPAD
F531 17   0415              LBSR    KBINCH
F534 39                    RTS

F535 17   0645      DSAVE   LBSR    PGMSAV     DISABLE CMOS MEMORY
F538 20   CA               BRA     ANOTHR

F53A 108E DE20      CRLF    LDY     #ACIA
F53E 17   0989             LBSR    WFS
F541 0D 0A 00              FCB     $0D,$0A,$00
F544 39                    RTS

F545 A6   80        OUTDAT  LDA     X+
F547 17   09BE             LBSR    WRC        OUTPUT CHAR.
F54A 5A                    DECB
F54B 26   F8               BNE     OUTDAT
F54D 39                    RTS

F54E 9F   00        OUT4S   STX     INDEX
F550 108E DE20             LDY     #ACIA
F554 17   0973             LBSR    WFS
F557 20 20 20 20           FCB     $20,$20,$20,$20,$00
F558 00
F55C 9E   00               LDX     INDEX
F55E 39                    RTS

F55F 86   3F        ERROR7  LDA     #'?
F561 17   09A4             LBSR    WRC
F564 16   FF20             LBRA    OUTSS

F567                END

0 ERROR(S) DETECTED

SYMBOL TABLE:

ACIA    DE20    ANOTHR  F504    BUFFER  0800    CALCII  F2D6    CHARIN  F52E
CRLF    F53A    DATBUF  070B    DSAVE   F535    END     F567    ERROR7  F55F
EXIT    F4E4    HEADER  F470    INDEX   0700    KBINCH  F949    KDAT0   0776
KEYPAD  DE2B    KOUT    F4B1    OUT4S   F54E    OUTDAT  F545    OUTSS   F487
PGMSAV  FB7D    PUTDAT  F46A    RDAT0   076C    REVFLG  0756    ROUT    F492
STARTC  FC00    STARTD  0743    UNPAKS  FBCC    WFS     FECA    WRC     FF0B
```

```
DIV151 F78E    DIV153 F799    DIV16  F77E    DIV163 F7A1    DIV165 F7AB
DIV167 F7AD
```

```
NOT FOUND
                        ****************************************************

                        *                    MUL16

                        * THIS ROUTINE IS A 16 BIT BY 16 BIT MULTIPLY!
                        * ONE NUMBER IS POINTED TO BY X, THE OTHER BY Y.
                        * U POINTS TO STORAGE FOR THE RESULT.  THIS
                        * ROUTINE GENERATES A 32 BIT UNSIGNED RESULT.

                        *  (A:B) X (C:D) =          BDH:BDL
                        *                 +     BCH:BCL
                        *                 +     ADH:ADL
                        *                 + ACH:ACL
                        *                   ---------------

                        ****************************************************

  F7C0                          ORG     $F7C0

  F7C0 6F   C4          MUL16   CLR     0,U
  F7C2 6F   41                  CLR     1,U
  F7C4 A6   01                  LDA     1,X       LEAST SIGN. BYTE NUMBER A
  F7C6 E6   21                  LDB     1,Y       LEAST SIGN. BYTE NUMBER B
  F7C8 3D                       MUL
  F7C9 ED   42                  STD     2,U       SAVE RESULT
  F7CB A6   84                  LDA     0,X       MOST SIGN. BYTE NUMBER A
  F7CD E6   21                  LDB     1,Y       LEAST SIGN. BYTE NUMBER B
  F7CF 3D                       MUL
  F7D0 E3   41                  ADDD    1,U
  F7D2 ED   41                  STD     1,U
  F7D4 24   02                  BCC     AB1
  F7D6 6C   C4                  INC     0,U

  F7D8 A6   01          AB1     LDA     1,X       LEAST SIGN. BYTE NUMBER A
  F7DA E6   A4                  LDB     0,Y       MOST SIGN. BYTE NUMBER B
  F7DC 3D                       MUL
  F7DD E3   41                  ADDD    1,U
  F7DF ED   41                  STD     1,U
  F7E1 24   02                  BCC     AB2
  F7E3 6C   C4                  INC     0,U

  F7E5 A6   84          AB2     LDA     0,X       MOST SIGN. BYTE NUMBER A
  F7E7 E6   A4                  LDB     0,Y       MOST SIGN. BYTE NUMBER B
  F7E9 3D                       MUL
  F7EA E3   C4                  ADDD    0,U
  F7EC ED   C4                  STD     0,U

  F7EE 39                       RTS

  F7EF                  END

0 ERROR(S) DETECTED

SYMBOL TABLE:

        F7D8    AB2     F7E5    END     F7EF    MUL16   F7C0
```

```
                ************************************************

                *                    ASTIMER

                * THIS ROUTINE INITIALIZES THE TIMER IN THE
                * MODULAS ONE SYSTEM, AND ALSO SETS TIMER
                * PERIOD AND CHECKS FOR TIMEOUT OF TIMER 0.
                * HANDLING OF TIMER ONE AND TWO CAN BE DONE
                * IF DESIRED. SEE DATA SHEETS FOR TIMER AND
                * MODULE 1140 MANUAL

                ************************************************


                * SYSTEM EQUATES

          0034  CTRLT0  EQU     $34         INITIAL CONTROL STATE TIMER 0
          0060  CTRLT1  EQU     $60         INITIAL CONTROL STATE TIMER 1
          0099  CTRLT2  EQU     $99         INITIAL CONTROL STATE TIMER 2
          0025  MSBT0   EQU     $25         MOST SIGNIFICANT BYTE COUNTER 0
          00B0  LSBT0   EQU     $80         LEAST SIGN. BYTE COUNTER 0
          00FF  LSBT1   EQU     $FF         LEAST SIGN. BYTE COUNTER 1
          0010  MSBT2   EQU     $10         MOST SIGN. BYTE COUNTER 2

                * ADDRESSES

          DE2C  CT0     EQU     $DE2C       COUNTER 0 ADDRESS
          DE2D  CT1     EQU     $DE2D       COUNTER 1
          DE2E  CT2     EQU     $DE2E       COUNTER 2
          DE2F  TIMER   EQU     $DE2F       CONTROL WORD FOR PROGRAMMING
          DE29  CRA     EQU     $DE29       PIA CONTROL REGISTER A
          DE28  KPD     EQU     $DE28       DATA REGISTER A--KEYPAD

                *  INITIALIZATION

F800                    ORG     $F800


F800 86   34    INTIME  LDA     #CTRLT0     RESET TIMERS
F802 B7   DE2F          STA     TIMER
F805 86   60            LDA     #CTRLT1
F807 B7   DE2F          STA     TIMER
F80A 86   99            LDA     #CTRLT2
F80C B7   DE2F          STA     TIMER
F80F 86   80            LDA     #LSBT0      SET INITIAL VALUES
F811 B7   DE2C          STA     CT0
F814 86   25            LDA     #MSBT0
F816 B7   DE2C          STA     CT0
F819 86   FF            LDA     #LSBT1
F81B B7   DE2D          STA     CT1
F81E 86   10            LDA     #MSBT2
F820 B7   DE2E          STA     CT2
F823 39                 RTS


                ************************************************
```

```
                        * WHEN THE TIMER IS READ, IT INDICATES THE
                        * NUMBER OF CLOCK PERIODS ELAPSED SINCE THE
                        * LAST INTERRUPT (TIMEOUT) WAS GENERATED.
                        * HERE, THE TIMER HAS BEEN INITIALIZED TO
                        * GENERATE A TIMEOUT PULSE EVERY SECOND.
                        * THE INPUT CLOCK IS A 9600 HERTZ PULSE INPUT
                        * FROM THE BAUD RATE GENERATOR, AND THE TIMEOUT
                        * APPEARS AT CA1 OF THE PIA.

                        * TO CHANGE THE TIMER PERIOD, THE COUNTER IS
                        * LOADED WITH A NEW VALUE. THIS NEW COUNT
                        * IS EFFECTIVE AFTER THE NEXT TIMEOUT PERIOD.

                        ************************************************

                        * READ TIMER--A AND B REGISTERS DESTROYED

F824 4F                 RDTIME  CLRA
F825 B7   DE2F                  STA     TIMER       LATCH COUNTER 0
F828 F6   DE2C                  LDB     CT0         GET LSB OF COUNT
F82B B6   DE2C                  LDA     CT0         GET MSB OF COUNT
F82E 39                         RTS

                        * CHANGE TIMER PERIOD--A  DESTROYED
                        *                       X CONTAINS LOCATION
                        *                         OF NEW VALUE

F82F A6   01            CGTIME  LDA     1,X         GET LSB OF NEW VALUE
F831 B7   DE2C                  STA     CT0
F834 A6   84                    LDA     X           GET MSB OF NEW VALUE
F836 B7   DE2C                  STA     CT0         COUNTER 0 NOW CONTAINS NEW PERIOD

F839 B6   DE29          TIMCHK  LDA     CRA         CHECK FOR TIME OUT
F83C 48                         ASLA
F83D 24   FA                    BCC     TIMCHK
F83F B6   DE2B                  LDA     KPD         CLEAR IRQ
F842 39                         RTS                 TIMER NOW OPERATING AT NEW PERIOD

                        * TIMCHK IS ALSO USED AS SUBROUTINE CALL
                        *        FOR TIMING NEEDS.

                                END

0 ERROR(S) DETECTED

SYMBOL TABLE:

CGTIME F82F    CRA     DE29    CT0     DE2C    CT1     DE2D    CT2     DE2E
CTRLT0 0034    CTRLT1  0060    CTRLT2  0099    INTIME  FB00    KPD     DE28
LSBT0  0080    LSBT1   00FF    MSBT0   0025    MSBT2   0010    RDTIME  F824
TIMCHK F839    TIMER   DE2F
```

NO SUCH FILE

```
                        ********************************************************

                        *                    ASATOD

                        * THIS ROUTINE PROVIDES A UTILITY PROGRAM TO
                        * OPERATE THE ADAPTIVE SYSTEMS MODULAS ONE
                        * A TO D MODULE #1642.

                        ********************************************************


                        * SYSTEM EQUATES

                   DE10 DADC     EQU     $DE10       BASE ADDRESS OF 1642 MODULE = PIA

0700                            ORG     $0700

0700                    INDEX   RMB     2           RESERVE TWO LOCATIONS FOR X TEMP
0702                    ADCVAL  RMB     2           LOCATION FOR LATEST ADC VALUE
0704                    CHNUM   RMB     1           STORAGE FOR CURRENT CHANNEL

F843                            ORG     $F843

                   0007         SETDP   $07

                        * INITIALIZATION---ASSUMES RESET HAS OCCURRED

F843 8E   DE10       INITAD  LDX     #DADC       GET ADDRESS OF PIA
F846 CC   34F0                LDD     #$34F0
F849 A7   01                  STA     1,X         SET A SIDE--ALL INPUT,CA2 OUTPUT
F84B E7   02                  STB     2,X         SET B SIDE--PB4-7 OUT,PB0-3 IN
F84D 86   3C                  LDA     #$3C
F84F A7   03                  STA     3,X         SET CB2--OUTPUT, IRQ'S MASKED
F851 39                       RTS

                        * CHANNEL SELECTION

F852 9F   00         CHSELT   STX     INDEX       SAVE INDEX
F854 8E   DE10                LDX     #DADC       GET BASE ADDRESS
F857 96   04                  LDA     CHNUM
F859 48                       ASLA
F85A 48                       ASLA
F85B 48                       ASLA
F85C 48                       ASLA
F85D A7   02                  STA     2,X         PUT IN CHANNEL SELECT
F85F C6   08                  LDB     #8          DO APPROX. 50 MICROSEC DELAY
F861 5A              ADC1     DECB                FOR OP AMP TO STABILIZE
F862 26   FD                  BNE     ADC1
F864 9E   00                  LDX     INDEX       RESTORE INDEX
F866 39                       RTS

                        * SELECT SAMPLING MODE

F867 9F   00         SMSELT   STX     INDEX       SAVE INDEX
F869 8E   DE10                LDX     #DADC       GET BASE ADDRESS
F86C CC   343C                LDD     #$343C
F86F A7   01                  STA     1,X         SET CA1-LO FOR A/D SAMPLING
```

```
F871 12                    NOP
F872 12                    NOP
F873 12                    NOP
F874 E7   03               STB    3,X        RESET ADC
F876 9E   00               LDX    INDEX      RESTORE INDEX
F878 39                    RTS

                    * A/D CONVERSION

F879 9F   00       CONVRT  STX    INDEX      SAVE INDEX
F87B 8E   DE10             LDX    #DADC
F87E CC   3C34             LDD    #$3C34
F881 A7   01               STA    1,X        SET CA2-HI FOR HOLD MODE
F883 B6   04               LDA    #$4
F885 E7   03               STB    3,X        START ADC CONVERSION (CB2-LO)
F887 E6   03       ADC3    LDB    3,X        CECK FOR EOC
F889 2B   03               BMI    ADC4       IF RECEIVED--READ VALUE
F88B 4A                    DECA              IF NOT FOUND, LOOP
F88C 26   F9               BNE    ADC3       UNTIL LOOP COUNTER = 0

F88E A6   02       ADC4    LDA    2,X        READ UPPER 4 BITS
F890 8A   F0               ORA    #$F0       MASK OUTPUT BITS
F892 E6   84               LDB    0,X        GET LOWER 8 BITS
F894 40                    NEGA              DATA IS COMPLEMENTARY OFFSET BINAR

Y
F895 50                    NEGB              MUST BE NEGATED
F896 82   00               SBCA   #0         ADJUST OVERFLOW
F898 DD   02               STD    ADCVAL     SAVE RESULT
F89A 9E   00               LDX    INDEX      RESTORE INDEX
F89C 39                    RTS


                           END

0 ERROR(S) DETECTED

SYMBOL TABLE:

ADC1   F861   ADC3   F887   ADC4   F88E   ADCVAL 0702   CHNUM  0704
CHSELT F852   CONVRT F879   DADC   DE10   INDEX  0700   INITAD F843
SMSELT F867
```

```
                        ********************************************

                        *                ASDTOA

                        * THIS ROUTINE PROVIDES A UTILITY PROGRAM TO
                        * OPERATE THE ADAPTIVE SYSTEMS MODULAS ONE
                        * D TO A MODULE #1614

                        ********************************************


                                OPT     PAG

                        * SYSTEM EQUATES

                   DE50 DDAC    EQU     $DE50       DAC BASE ADDRESS
                   DE55 DSWITC  EQU     $DE55       ANALOG SWITCH SELECT ADDRESS
                   0700 INDEX   EQU     $0700       TEMP STORAGE FOR INDEX

0705                            ORG     $0705
0705                    SWNUM   RMB     1           STORAGE FOR LATEST SWITCH VALUE
0706                    DACVAL  RMB     2           STORAGE FOR LATEST INPUT VALUE
0708                    DACOLD  RMB     2           STORAGE FOR PREVIOUS INPUT VALUE

                   0007         SETDP   $07

F89D                            ORG     $F89D

                        * INITIALIZATION

F89D BE   DE50          INITDA  LDX     #DDAC       GET BASE ADDRESS
F8A0 4F                         CLRA
F8A1 C6   06                    LDB     #6          ZERO DAC'S AND TURN SWITCH OFF
F8A3 8D   05                    BSR     DACINZ
F8A5 C6   0A                    LDB     #10
F8A7 8E   0700                  LDX     #INDEX

F8AA A7   80            DACINZ  STA     X+
F8AC 5A                         DECB
F8AD 26   FB                    BNE     DACINZ
F8AF 39                         RTS

                        * TURN SWITCH ON

F8B0 9F   00            SWNSET  STX     INDEX       SAVE INDEX
F8B2 8E   DE55                  LDX     #DSWITC     POINT TO SWITCH SELECT
F8B5 96   05                    LDA     SWNUM       GET SWITCH NUMBER
F8B7 46                         RORA                MOVE NUMBER TO BITS 6 AND 7
F8B8 46                         RORA
F8B9 46                         RORA
F8BA A7   84                    STA     X           SEND TO SWITCH SELECT
F8BC 9E   00                    LDX     INDEX       RESTORE INDEX
F8BE 39                         RTS

                        * TURN SWITCH OFF--ALTERNATE TO SWNSET WITH 00
                        *           DOES NOT CHANGE CONTENTS OF SWNUM
```

```
F8BF 9F   00       SWNZER  STX    INDEX     SAVE INDEX
F8C1 8E   DE55             LDX    #DSWITC
F8C4 86   00               LDA    #$00
F8C6 A7   84               STA    0,X
F8C8 9E   00               LDX    INDEX     RESTORE INDEX
F8CA 39                    RTS

                   * LOAD DAC VALUE

F8CB 9F   00       LDDAC   STX    INDEX     SAVE INDEX
F8CD 8E   DE50             LDX    #DDAC     POINT TO DAC 1
F8D0 D6   06               LDB    DACVAL    GET DAC INPUT
F8D2 D7   0B               STB    DACOLD
F8D4 96   07               LDA    DACVAL+1
F8D6 97   09               STA    DACOLD+1
F8D8 54                    LSRB             SHIFT SO THAT 2 LO  BITS ARE IN
F8D9 46                    RORA             BITS 6 AND 7 OF B AND 8 HI BITS
F8DA 56                    RORB             ARE IN A
F8DB 46                    RORA
F8DC 56                    RORB
F8DD ED   84               STD    X         OUTPUT VALUE TO DAC
F8DF 9E   00               LDX    INDEX     RESTORE INDEX
F8E1 39                    RTS

                           END

0 ERROR(S) DETECTED
```

SYMBOL TABLE:

```
DACINZ F8AA    DACOLD 0708    DACVAL 0706    DDAC   DE50   DSWITC DE55
INDEX  0700    INITDA F89D    LDDAC  F8CB    SWNSET FBB0   SWNUM  0705
SWNZER FBBF
```

```
                        ***********************************************

                        *                SAVECK

                        * THIS ROUTINE CHECKS FOR DISABLING OF THE
                        * CMOS MEMORY ON STARTUP. THE CONTENTS OF
                        * THIS CMOS MEMORY ARE SAVED BY BISABLING
                        * THE INPUT TO THE MEMORY. THIS IS DONE BY
                        * CLOSURE OF THE STORE KEY (ALTERNATE ACTION)
                        * PRIOR TO POWER-OFF OR WHENEVER DESIRED.
                        * ON RESET OR POWER-UP, THE UNIT WILL CHECK
                        * AND REQUEST RELEASE IF NEEDED. THAT IS THE
                        * FUNCTION OF THIS ROUTINE.

                        ***********************************************


                        * SYSTEM EQUATES

                   DE2A ORB      EQU     $DE2A      ADDRESS OF DATA REG OF PIA
                   DE20 ACIA     EQU     $DE20
                   FECA WFS      EQU     $FECA      ROUTINE TO WRITE STRING
                   070A SAVFLG   EQU     $070A

                   0007          SETDP   $07

FBF0                             ORG     $FBF0

                        * CHECK FOR SAVE AND REQUEST RELEASE
                        *        ASSUMES INITIALIZATION COMPLETE!

FBF0 108E DE20     SAVECK LDY     #ACIA      POINT TO COMMUNICATIONS REGISTER
FBF4 F6   DE2A            LDB     ORB        GET PIA B DATA
FBF7 C4   40              ANDB    #$40       IS BIT 6 HI?
FBF9 27   04              BEQ     CONT1      IF NOT HIGH, MEMORY HAS BEEN SAVED

FBFB 0F   0A              CLR     SAVFLG
FBFD 20   31              BRA     CONT       MEMORY AVAILABLE-CONTINUE
FBFF 86   FF       CONT1  LDA     #$FF       SET FLAG .
F901 97   0A              STA     SAVFLG
F903 17   05C4            LBSR    WFS        REQUEST CLEARANCE OF DISABLE
F906 4D 45 4D 4F          FCC     'MEMORY NOT AVAILABLE--UNSAVE!'
F90A 52 59 20 4E
F90E 4F 54 20 41
F912 56 41 49 4C
F916 41 42 4C 45
F91A 2D 2D 55 4E
F91E 53 41 56 45
F922 21
F923 00                   FCB     0
F924 86   04       CHECK  LDA     #$4
F926 C6   40       CHECK1 LDB     #$40
F928 F5   DE2A            BITB    ORB
F92B 27   F7              BEQ     CHECK
F92D 4A                   DECA
F92E 26   F6              BNE     CHECK1     CHECK FOUR TIMES FOR COMPLETION
F930 17   0597     CONT   LBSR    WFS
F933 0D 0A                FCB     $0D,$0A
```

```
F935 52 45 41 44            FCC     'READY'
F939 59
F93A 00                     FCB     0
F93B 39                     RTS

                            END

0 ERROR(S) DETECTED

SYMBOL TABLE:

ACIA    DE20    CHECK   F924    CHECK1  F926    CONT    F930    CONT1   F8FF
ORB     DE2A    SAVECK  FBF0    SAVFLG  070A    WFS     FECA
```

```
                        **********************************************

                        *                KPDCTL

                        * THIS ROUTINE CONTROLS THE OPERATION OF THE
                        * KEYPAD ON THE PORTABLE INSTRUMENT. THIS
                        * UTILITY IS CONCERNED ONLY WITH THE IMMEDIATE
                        * OPERATION OF THE KEYPAD AND THE ENTRY OF A
                        * SINGLE CHARACTER, AND ITS TRANSLATION INTO
                        * ASCII. OTHER ASPECTS OF KEYPAD USAGE ARE TO
                        * BE CONTROLLED BY THE CALLING ROUTINES.

                        **********************************************


                        * SYSTEM EQUATES

                   DE2B KEYPAD  EQU    $DE2B     DRA OF PIA ON 1140 MODULE
                   0700 INDEX   EQU    $0700

                   0007         SETDP  $07

F93C                            ORG    $F93C

                        * INITIALIZATION--ASSUMES RESET

F93C 8E   DE2B     INITKP LDX    #KEYPAD   GET PIA BASE ADDRESS
F93F 86   14               LDA    #$14      A SIDE-INPUT,IRQ'S MASKED
F941 A7   01               STA    1,X       CA1 GOES LO,CA2 GOES HI
F943 CC   3F04             LDD    #$3F04    B SIDE-2 IN, 6 OUT MASK IRQ'S
F946 ED   02               STD    2,X       CB1 AND CB2 GO L0
F948 39                    RTS

                        * READ KEYPAD--NO MATCH SHOWN BY ZERO BIT SET

F949 9F   00       KBINCH  STX    INDEX     SAVE INDEX
F94B 34   40               PSHS   U         SAVE U
F94D CE   DE2B             LDU    #KEYPAD
F950 86   40               LDA    #$40      SET MASK
F952 A5   41       CHARIN  BITA   1,U       DO WE HAVE A CHARACTER(CA2-HI)
F954 27   FC               BEQ    CHARIN    LOOP, IF NOT
F956 A6   C4               LDA    U         ELSE, GET CHARACTER
F958 8E   F96D             LDX    #KEYTBL

F95B A1   81       KBIN1   CMPA   X++
F95D 27   0A               BEQ    KBIN2
F95F BC   F989             CPX    KEYTBL+28 HAVE WE REACHED END OF TABLE?
F962 26   F7               BNE    KBIN1
F964 5F                    CLRB             SHOW NO MATCH FOUND!
F965 9E   00       KBIN3   LDX    INDEX     RESTORE INDEX
F967 35   C0               PULS   U,PC      RESTORE U REGISTER, RETURN

F969 E6   1F       KBIN2   LDB    -1,X      SHOW MATCH
F968 20   FB               BRA    KBIN3

                        * TABLE TO CONVERT KEYPAD VALUE TO ASCII

F96D 11 0D         KEYTBL  FCB    $11,$0D
```

```
F96F 12 33                      FCB     $12,$33
F971 14 36                      FCB     $14,$36
F973 18 39                      FCB     $18,$39
F975 21 30                      FCB     $21,$30
F977 22 32                      FCB     $22,$32
F979 24 35                      FCB     $24,$35
F97B 28 38                      FCB     $28,38
F97D 41 7F                      FCB     $41,$7F
F97F 42 31                      FCB     $42,$31
F981 44 34                      FCB     $44,$34
F983 48 37                      FCB     $48,$37
F985 81 4A                      FCB     $81,$4A
F987 82 48                      FCB     $82,$48

                                END

0 ERROR(S) DETECTED

SYMBOL TABLE:

CHARIN F952    INDEX  0700    INITKP F93C    KBIN1  F95B    KBIN2  F969
KBIN3  F965    KBINCH F949    KEYPAD DE28    KEYTBL F96D
```

```
                    **************************************************

                    *                    GETDATA

                    * THIS ROUTINE GETS A DATA STRING FROM THE
                    * KEYPAD OF THE PORTABLE INSTRUMENT. ENTRY
                    * REQUIRES THAT B CONTAIN THE NUMBER OF CHAR.
                    * REQUESTED AND X CONTAINS THE STARTING ADDRESS
                    * FOR STORAGE. THE ROUTINE FORMATS THE STRING
                    * SO THAT LEADING ZEROS ARE INSERTED TO FILL
                    * THE REQUESTED DATA BLOCK. STORAGE IS IN THE
                    * FORM OF ASCII CHARACTERS.

                    * INCLUDED IN THIS ROUTINE IS A SUBROUTINE TO
                    * ALLOW FOR APPROXIMATELY 100 MILLISEC PER
                    * CHARACTER

                    **************************************************


                    * SYSTEM EQUATES

                F949  KBINCH  EQU     $F949       INPUT CHARACTER FROM KEYPAD
                FECA  WFS     EQU     $FECA       STRING OUTPUT ROUTINE
                0780  INDEX1  EQU     $0780       TEMPORARY STORAGE FOR INDEX
                FA0C  CMDADR  EQU     ERROR+$A
                DE29  KEYPAD  EQU     $DE29
                FF0B  WRC     EQU     $FF0B

070B                          ORG     $070B

070B                DATBUF    RMB     2           STORAGE FOR LATEST BUFFER ADDRESS
070D                TCOUNT    RMB     1           STORAGE FOR WORKING COUNT
070E                TCHAR     RMB     1           STORAGE FOR WORKING CHARACTER
070F                TCHCNT    RMB     1           COUNTER FOR ACESSES TO CHAR.
0710                TBUFFR    RMB     33          BUFFER AREA FOR STRING STORAGE
0731                RUNFLG    RMB     2           FLAG TO INDICATE RUN STATUS

                0007          SETDP   $07

F9A3                          ORG     $F9A3

F9A3 9E   0B        GETDAT    LDX     DATBUF      GET STORAGE POINTER
F9A5 D7   0D                  STB     TCOUNT
F9A7 9F   B0                  STX     INDEX1      SAVE INDEX
F9A9 8E   0710                LDX     #TBUFFR     POINT TO TEMPORARY BUFFER
F9AC 0F   0E                  CLR     TCHAR
F9AE B6   DE2B                LDA     KEYPAD      CLEAR ANY RESIDUAL CHARACTER IRQ
F9B1 BD   96        DATA1     BSR     KBINCH      GET A CHARACTER
F9B3 27   4D                  BEQ     ERROR       ZERO BIT IS ERROR FLAG FOR KBINCH
>F9B5 17  007F                LBSR    CHARCK      CHECK FOR TIMEOUT
F9B8 0A   0D                  DEC     TCOUNT      UPDATE CHAR. COUNT
F9BA 26   2E                  BNE     NXTCHR
F9BC C1   0D                  CMPB    #$0D
F9BE 26   5A                  BNE     ERROR1      LAST CHAR. MUST BE CR
F9C0 E7   B0        RET       STB     X+
F9C2 34   40                  PSHS    U           SAVE U
F9C4 1F   13                  TFR     X,U
```

```
F9C6 9E   80            LDX     INDEX1      POINT TO STORAGE AREA
F9C8 DF   80            STU     INDEX1
F9CA D6   0D            LDB     TCOUNT      FETCH REMAINING NUMBER OF CHAR
F9CC 27   07            BEQ     CHARS1
F9CE 86   30            LDA     #$30        LOAD A WITH ASCII ZERO
F9D0 A7   80    ZEROS   STA     X+
F9D2 5A                 DECB
F9D3 26   FB            BNE     ZEROS
F9D5 34   20    CHARS1  PSHS    Y           SAVE Y
F9D7 108E 0710          LDY     #TBUFFR
F9DB A6   A0    CHARS   LDA     Y+
F9DD A7   80            STA     X+
F9DF 109C 80            CMPY    INDEX1
F9E2 27   02            BEQ     RET1
F9E4 20   F5            BRA     CHARS
F9E6 9F   0B    RET1    STX     DATBUF
F9E8 35   E0            PULS    Y,U,PC      CLEAN STACK, RETURN

F9EA C1   0D    NXTCHR  CMPB    #$0D        IS CHAR. A CR
F9EC 26   02            BNE     NXTONE
F9EE 20   D0            BRA     RET

F9F0 C1   7F    NXTONE  CMPB    #$7F        IS IT A DELETE
F9F2 26   02            BNE     CHAR
F9F4 5F                 CLRB                SHOW CANCELLATION OF ENTRY
F9F5 39                 RTS

F9F6 E7   80    CHAR    STB     X+          SAVE CHARACTER
F9F8 1F   98            TFR     B,A
F9FA 17   050B          LBSR    WRC         ECHO CHARACTER
F9FD 58                 ASLB
F9FE 2B   4D            BMI     CMD         IF CMD, PROCESS
FA00 20   AF            BRA     DATA1

FA02 17   04C5  ERROR   LBSR    WFS         OUTPUT STRING
FA05 49 4C 4C 45        FCC     'ILLEGAL CHARACTER!'
FA09 47 41 4C 20
FA0D 43 48 41 52
FA11 41 43 54 45
FA15 52 21
FA17 00                 FCB     0
FA18 20   18            BRA     WAIT

FA1A 17   04AD  ERROR1  LBSR    WFS
FA1D 54 30 30 20        FCC     'T00 MANY CHARACTERS!'
FA21 4D 41 4E 59
FA25 20 43 48 41
FA29 52 41 43 54
FA2D 45 52 53 21
FA31 00                 FCB     0

FA32 17   FF14  WAIT    LBSR    KBINCH      WAIT FOR ANY CHAR. INPUT
FA35 5F                 CLRB                SHOW ERROR
FA36 39                 RTS

FA37 D1   0E    CHARCK  CMPB    TCHAR       COMPARE TO PREVIOUS CHAR.
FA39 27   07            BEQ     CKMATC
FA3B D7   0E    NEW     STB     TCHAR       SAVE CHAR. IF NO MATCH
FA3D 86   03            LDA     #3
```

```
FA3F 97   0F            STA    TCHCNT    SET FOR THREE INPUTS OF CHAR.
FA41 39                 RTS

FA42 0A   0F      CKMATC DEC    TCHCNT
FA44 27   F5             BEQ    NEW
FA46 35   02             PULS   A
FA48 35   02             PULS   A
FA4A 16   FF64           LBRA   DATA1

FA4D 8E   FA0C    CMD    LDX    #CMDADR   GET CMD BASE ADDRESS
FA50 57                  ASRB             RESTORE CHAR
FA51 3A                  ABX
FA52 6E   84             JMP    X


FA54 20   07      CMDH   BRA    CMDH1     HALT COMMAND ROUTINE

                  ************************************************

                  * LOCATION RUNFLG MUST BE LOADED WITH THE
                  * ADDRESS OF THE ROUTINE TO BE STARTED ON RUN
                  * COMMAND. ELSE, AN ERROR WILL BE RETURNED.

                  ************************************************

FA56 DC   31      CMDR   LDD    RUNFLG    RUN COMMAND ROUTINE
FA58 27   0C             BEQ    ERROR2
FA5A 34   06             PSHS   D         PUT D INTO SUBROUTINE RETURN CALL
FA5C 39                  RTS

                  ************************************************

                  * THE HALT COMMAND ENTERS A LOOP AND STAYS THERE
                  * UNTIL A RUN COMMAND IS RECEIVED.
                  * UPON RECEIPT OF THE R CMD. THE PROCESSOR WILL
                  * RESUME AT THE ROUTINE THAT WAS IN OPERATION
                  * WHEN HALT WAS CALLED.  THIS IS DONE BY
                  * REPORTING AN ERROR AND LETTING THE ROUTINE
                  * USE ITS EXCEPTION CALL.

                  ************************************************

FA5D 17   FEE9    CMDH1  LBSR   KBINCH    WAIT FOR A CHARACTER
FA60 C1   4A             CMPB   #$4A      IS IT AN R?
FA62 26   F9             BNE    CMDH1     IF NOT LOOP AGAIN
FA64 5F                  CLRB             ELSE, SHOW ERROR
FA65 39                  RTS              AND RETURN

FA66 20   9A      ERROR2 BRA    ERROR

                         END

0 ERROR(S) DETECTED

SYMBOL TABLE:

CHAR    F9F6   CHARCK FA37   CHARS  F9DB   CHARS1 F9D5   CKMATC FA42
CMD     FA4D   CMDADR FA0C   CMDH   FA54   CMDH1  FA5D   CMDR   FA56
DATA1   F9B1   DATBUF 070B   ERROR  FA02   ERROR1 FA1A   ERROR2 FA66
```

```
GETDAT F9A3    INDEX1 0780    KBINCH F949    KEYPAD DE28    NEW    FA3B
NXTCHR F9EA    NXTONE F9F0    RET    F9C0    RET1   F9E6    RUNFLG 0731
TBUFFR 0710    TCHAR  070E    TCHCNT 070F    TCOUNT 070D    WAIT   FA32
WFC    FECA    WRC    FF0B    ZEROS  F9D0
```

```
NO SUCH FILE
                        **************************************************

                        *                  CLRBUF

                        * THIS ROUTINE CLEARS AREAS OF MEMORY IN THE AS
                        * SYSTEM. THE STARTING AND ENDING ADDRESSES ARE TO
                        * BE PLACED IN THE LOCATIONS INDICATED, BY THE
                        * CALLING PROGRAM. A AND X ARE DESTROYED.

                        **************************************************

  07DB                          ORG     $07DB

                0007            SETDP   $07

  07DB                  TBUFST  RMB     2           START ADDRESS TO BE HERE
  07DA                  TBUFND  RMB     2           END ADDRESS TO BE HERE

  FA69                          ORG     $FA69

  FA69 34   40                  PSHS    U           SAVE U REGISTER
  FA6B DE   DA                  LDU     TBUFND      LOAD U WITH END ADDRESS
  FA6D 4F                       CLRA
  FA6E 36   02          NEXT    PSHU    A           STORE A IN LAST LOCATION
  FA70 1193 DB                  CMPU    TBUFST      HAVE WE DONE ALL
  FA73 26   F9                  BNE     NEXT        LOOP IF NOT DONE
  FA75 36   02                  PSHU    A
  FA77 35   C0                  PULS    U,PC        RESTORE U, RETURN

                                END

0 ERROR(S) DETECTED

SYMBOL TABLE:

NEXT    FA6E    TBUFND 07DA    TBUFST 07DB
```

```
                        ********************************************

                        *           BIN2BCD

                        * THIS ROUTINE CONVERTS A 16 BIT BINARY
                        * NUMBER TO BCD AND STORES THE RESULTING
                        * 5 CHARACTERS.
                        * ON START, D CONTAINS THE BINARY NUMBER,
                        * AND X CONTAINS THE POINTER TO DECIMAL
                        * STORAGE

                        ********************************************

                        * SYSTEM EQUATES

                  FA79  K10K     EQU     $FA79

                        * TEMPORARY STORAGE

073E                            ORG     $073E

073E                    SAVEA   RMB     1           ACCUMULATOR A
073F                    SAVEX   RMB     2           STORE DATA POINTER
0741                    SAVEX1  RMB     2           POINTER TO CONSTANTS

                  0007          SETDP   $07

FAB1                            ORG     $FAB1

FAB1 9F   3F            CVBTD   STX     SAVEX       SAVE DATA POINTER
FAB3 8E   FA79                  LDX     #K10K       POINT TO CONSTANTS
FAB6 0F   3E            CVDEC1  CLR     SAVEA       INITIALIZE DEC CHAR
FAB8 A3   84            CVDEC2  SUBD    X
FABA 25   04                    BCS     CVDEC5      OVERFLOW
FABC 0C   3E                    INC     SAVEA       INC CHAR BEING BUILT
FABE 20   F8                    BRA     CVDEC2

FAC0 E3   84            CVDEC5  ADDD    X           RESTORE PARTIAL RESULT
FAC2 36   02                    PSHU    A           SAVE A REGISTER
FAC4 9F   41                    STX     SAVEX1
FAC6 9E   3F                    LDX     SAVEX       POINT TO STORAGE FOR RESULT
FAC8 96   3E                    LDA     SAVEA
FACA 8B   30                    ADDA    #$30        MAKE ASCII CHARACTER
FACC A7   84                    STA     X
FACE 37   02                    PULU    A           RESTORE A REGISTER
FAD0 30   01                    LEAX    1,X         INCREMENT X
FAD2 9F   3F                    STX     SAVEX
FAD4 9E   41                    LDX     SAVEX1      POINT TO CONSTANTS
FAD6 30   02                    LEAX    2,X
FAD8 8C   FAB9                  CPX     #K10K+10    ARE WE DONE
FADB 26   D9                    BNE     CVDEC1
FADD 39                         RTS


                                END

0 ERROR(S) DETECTED
```

```
SYMBOL TABLE:

CVBTD   FAB1    CVDEC1 FAB6    CVDEC2 FAB8    CVDEC5 FAC0    K10K    FA79
SAVEA   073E    SAVEX  073F    SAVEX1 0741
```

```
                        ****************************************

                        *               BCD2BIN
                        * THIS ROUTINE CONVERTS A STRING OF 5
                        * ASCII NUMBERS TO A 16 BIT BINARY VALUE.
                        * THE INITIAL STRING SHOULD NOT EXCEED
                        * 65,535.
                        * X SHOULD POINT TO THE START OF THE
                        * ASCII STRING.
                        * THE RESULT WILL BE IN D.

                        ****************************************

                        * TEMPORARY STORAGE

073A                            ORG     $073A

073A                    TEMP    RMB     1           BCD STORAGE
073B                    TEMP1   RMB     2           BINARY STORAGE
073D                    COUNT   RMB     1           STORAGE FOR CHARACTER COUNT

                0007            SETDP   $07

                        * CONSTANTS

FA79                            ORG     $FA79

FA79 2710               K10K    FDB     10000
FA7B 03E8                       FDB     1000
FA7D 0064                       FDB     100
FA7F 000A                       FDB     10
FA81 0001                       FDB     1

FA83 0F   3A          CVDTB   CLR     TEMP
FA85 0F   3B                  CLR     TEMP1
FA87 0F   3C                  CLR     TEMP1+1     INITIALIZE STORAGE
FA89 108E FA79                LDY     #K10K
FA8D 86   05                  LDA     #$05
FA8F 97   3D                  STA     COUNT

FA91 5F                 NEXT    CLRB
FA92 A6   80                  LDA     X+          GET ASCII CHARACTER
FA94 80   30                  SUBA    #$30        MAKE BCD
FA96 27   0E                  BEQ     SUM
FA98 97   3A                  STA     TEMP        SAVE IT
FA9A 4F                       CLRA
FA9B 5F                       CLRB
FA9C E3   A4          CV      ADDD    Y           GET CONSTANT VALUE
FA9E 0A   3A                  DEC     TEMP
FAA0 26   FA                  BNE     CV          ADD UNTIL DONE
FAA2 D3   3B                  ADDD    TEMP1
FAA4 DD   3B                  STD     TEMP1
FAA6 0A   3D          SUM     DEC     COUNT
FAA8 27   04                  BEQ     EXIT
FAAA 31   22                  LEAY    2,Y
FAAC 20   E3                  BRA     NEXT
```

```
  FAAE DC   3B       EXIT    LDD    TEMP1
  FAB0 39                    RTS

                             END

0 ERROR(S) DETECTED

SYMBOL TABLE:

COUNT  073D   CV     FA9C   CVDTB  FA83   EXIT   FAAE   K10K   FA79
NEXT   FA91   SUM    FAA6   TEMP   073A   TEMP1  073B
```

```
                        ********************************************************

                        *                    FIRQHDL

                        * THIS ROUTINE IS AN INTERRUPT HANDLER FOR FIRQ
                        * WHICH CHOOSES BETWEEN A JUMP TO MONITOR AND
                        * A REPEAT ROUTINE. SELECTION IS MADE BY
                        * MEANS OF THE STATUS OF THE FUNCT SWITCH ON THE
                        * PANEL OF THE PORTABLE INSTRUMENT. THE FIRQ IS
                        * ISSUED BY PRESSING THE KEY MARKED RPT(MONITOR).

                        ********************************************************


                        * SYSTEM EQUATES
                  07F6  EFIN     EQU     $07F6       STORAGE LOCATION FOR FIRQ VECTOR
                  DE2A  FRQFLG   EQU     $DE2A       PIA B SIDE DATA REGISTER
                  FC3C  NMI      EQU     $FC3C       ENTRY ROUTINE FOR AS01
                  0700  INDEX    EQU     $0700

0733                            ORG     $0733

                  0007          SETDP   $07

0733                    RUNCNT  RMB     1           NUMBER OF REPEATS PERFORMED
0734                    RPTADR  RMB     2           ADDRESS TO WHICH REPEAT GOES

FADE                            ORG     $FADE

                        * INITIALIZATION

FADE 9F   00            FRQINZ  STX     INDEX       SAVE X
FAE0 8E   FAF1                  LDX     #FRQVEC     GET ADDRESS FOR FIRQ ROUTINE
FAE3 36   10                    PSHU    X           SAVE IN STACK
FAE5 8E   FC3C                  LDX     #NMI        POINT TO MONITOR
FAE8 9F   34                    STX     RPTADR      SAVE AS DEFAULT FIRQ
FAEA 9E   00                    LDX     INDEX
FAEC 36   32                    PSHU    Y,X,A
FAEE 1C   0F                    ANDCC   #$0F        ENABLE FIRQ
FAF0 39                         RTS

                        * INTERRUPT HANDLER

FAF1 F6   DE2A          FRQVEC  LDB     FRQFLG      READ PIA FOR FUNCTION FLAG
FAF4 2A   06                    BPL     REPEAT      IF BIT7 = 0 REPEAT ROUTINE
FAF6 8E   FC3C          DEBUG   LDX     #NMI        DO MONITOR STARTUP
FAF9 AF   61                    STX     1,S         SET LOCATION TO JUMP TO
FAFB 3B                         RTI                 JUMP TO AS01

FAFC 0C   33            REPEAT  INC     RUNCNT
FAFE 6E   9F 0734               JMP     [RPTADR]



                                END

0 ERROR(S) DETECTED
```

```
SYMBOL TABLE:

DEBUG   FAF6    EFIN    07F6    FRQFLG DE2A    FRQINZ FADE    FRQVEC FAF1
INDEX   0700    NMI     FC3C    REPEAT FAFC    RPTADR 0734    RUNCNT 0733
```

```
                ********************************************************

                *                       STARTUP

                * THIS ROUTINE IS ENTERED WHEN RESET IS RECEIVED BY
                * THE ADAPTIVE SCIENCE SYSTEM. IT PERFORMS ALL
                * REQUIRED INITIALIZATIONS, AND THEN POINTS TO THE
                * START OF THE ROUTINE, AND WAITS FOR A RUN COMMAND

                ********************************************************

                * SYSTEM EQUATES

                FB00   INTIME  EQU    $FB00     INITIALIZE TIMER
                FB43   INITAD  EQU    $FB43     INITIALIZE A TO D
                FB9D   INITDA  EQU    $FB9D     INITIALIZE D TO A
                F93C   INITKP  EQU    $F93C     INITIALIZE KEYPAD
                07D8   TBUFST  EQU    $07D8
                07DA   TBUFND  EQU    $07DA
                FC00   RES     EQU    $FC00     INITIALIZE MONITOR AND ACIA
                FADE   FRQINZ  EQU    $FADE     SET UP FIRQ ROUTINE
                FBF0   SAVECK  EQU    $FBF0     CMOS MEMORY SAVE CHECK
                070A   SAVFLG  EQU    $070A
                FA69   CLRBUF  EQU    $FA69
                8010   BEGDAT  EQU    $8010     START OF CMOS DATA STORAGE
                0743   STARTD  EQU    $0743
                0731   RUNFLG  EQU    $0731
                F949   KBINCH  EQU    $F949
                FA56   CMDR    EQU    $FA56
                8002   SAVSTO  EQU    $8002     POINTER TO CMOS DATA STORAGE
                F000   BEGIN   EQU    $F000     LOCATION FOR START OF
                       *                          SEQUENCE
                       *SUBBEG  EQU   AF66
                0007           SETDP  $07

FB1F                           ORG    $FB1F

FB1F 36  20    STARTUP PSHU   Y
FB21 8D  BB            BSR    FRQINZ
FB23 86  07            LDA    #$07
FB25 1E  8B            EXG    A,DP
FB27 17  FCD6          LBSR   INTIME
FB2A 17  FD70 FB33     LBSR   INITDA
FB2D 17  FD13          LBSR   INITAD
FB30 17  FE09          LBSR   INITKP
FB33 8E  0000          LDX    #$0000
FB36 9F  D8            STX    TBUFST    POINT TO START OF SCRATCHPAD
FB38 8E  07D7          LDX    #$07D7
FB3B 9F  DA            STX    TBUFND    POINT TO END OF SCRATCHPAD
FB3D 17  FF29          LBSR   CLRBUF
FB40 8E  0B00          LDX    #$0B00
FB43 9F  D8            STX    TBUFST    POINT TO DATA STORAGE
FB45 8E  0FFF          LDX    #$0FFF
FB48 9F  DA            STX    TBUFND    POINT TO END OF DATA STORAGE
FB4A 17  FF1C          LBSR   CLRBUF
FB4D 17  FDA0          LBSR   SAVECK
FB50 0D  0A            TST    SAVFLG    HAS CMOS MEMORY BEEN PROTECTED?
FB52 26  20            BNE    SAVDAT    YES, GET START OF UNPROTECTED AREA
```

```
FB54 BE   B010            LDX    #BEGDAT
FB57 9F   43              STX    STARTD     SAVE POINTER TO DATA AREA
FB59 9F   D8              STX    TBUFST     CLEAR CMOS MEM.
FB5B BE   B7FF            LDX    #BEGDAT+$7EF
FB5E 9F   DA              STX    TBUFND
FB60 17   FF06            LBSR   CLRBUF
FB63 CC   F000    GO      LDD    #BEGIN
FB66 DD   31              STD    RUNFLG     POINT TO PROGRAM ENTRY
FB68 17   FDDE    GETR    LBSR   KBINCH
FB6B C1   4A              CMPB   #$4A
FB6D 26   F9              BNE    GETR       IF CHARACTER NOT R LOOP
FB6F 17   FEE4            LBSR   CMDR
FB72 27   AB              BEQ    STARTUP    TRY AGAIN, IF ERROR

FB74 BE   B002    SAVDAT  LDX    SAVST0     GET NEXT DATA LOCATION
FB77 9F   43              STX    STARTD     STORE IN POINTER
FB79 20   EB              BRA    GO


                          END

0 ERROR(S) DETECTED

SYMBOL TABLE:

BEGDAT B010   BEGIN  F000   CLRBUF FA69   CMDR   FA56   FRQINZ FADE
GETR   FB68   GO     FB63   INITAD F843   INITDA F89D   INITKP F93C
INTIME FB00   KBINCH F949   RES    FC00   RUNFLG 0731   SAVDAT FB74
SAVECK FBF0   SAVFLG 070A   SAVST0 8002   STARTD 0743   STARTU FB1F
TBUFND 07DA   TBUFST 07DB
```

```
                    **************************************************

                    *                    PGMSAVE

                    * THIS ROUTINE WILL DISABLE AND ENABLE ACCESS
                    * TO THE CMOS MEMORY WHILE THE PORTABLE UNIT
                    * IS POWERED UP.  TO RETAIN MEMORY DURING
                    * POWER OFF, THE SAVE BUTTON MUST BE DEPRESSED

                    **************************************************

                    * SYSTEM EQUATES

          DE2A      ORB       EQU     $DE2A       DATA REGISTER PIA B SIDE

FB7D                          ORG     $FB7D

FB7D CC   7F04    PGMSAV    LDD     #$7F04      DISABLE CMOS MEMORY
FB80 7F   DE2B              CLR     ORB+1       CLEAR CONTROL REGISTER B
FB83 FD   DE2A              STD     ORB         SET B SIDE BIT 7-IN, REST-OUT
FB86 86   3F                LDA     #$3F
FB88 B7   DE2A              STA     ORB         SET BIT 6 LO
FB8B 39                     RTS

FB8C 86   7F      UNSAVE    LDA     #$7F
FB8E B7   DE2A              STA     ORB         SET BIT 6 HI
FB91 39                     RTS

FB92 CC   3F04    EXT       LDD     #$3F04      RETURN TO EXTERNAL CONTROL
FB95 7F   DE2B              CLR     ORB+1       CLEAR CONTROL REGISTER B
FB98 FD   DE2A              STD     ORB         SET B SIDE 2-IN 6-OUT
FB9B 39                     RTS

                            END

0 ERROR(S) DETECTED

SYMBOL TABLE:

EXT     FB92    ORB     DE2A    PGMSAV  FB7D    UNSAVE  FB8C
```

```
                        ********************************************************
                        *                    UN/PACK
                        * THIS ROUTINE PACKS FOUR 6 BIT CHARACTERS(ASCII)
                        * INTO THREE 8 BIT BYTES, OR UNPACKS THREE EIGHT
                        * BIT BYTES INTO FOUR BYTES.  RECONVERSION TO ASCII
                        * IS ALSO DONE. ON ENTRY*
                        * FOR PACKING, X POINTS TO THE START OF DATA
                        *               Y POINTS TO THE START OF STORAGE
                        *               D CONTAINS THE NUMBER OF 4 CHAR BLOCKS

                        * FOR UNPACK,   X CONTAINS THE START OF STORAGE
                        *               Y CONTAINS THE START OF CHAR. STORAGE
                        *               D CONTAINS THE NUMBER OF 4 CHAR BLOCKS

                        ********************************************************

FB9C                            ORG     $FB9C

FB9C 4C                 PACKS   INCA                    ADJUST COUNT OF MS BYTE
FB9D 34  06                     PSHS    D               PUT COUNT ON THE STACK
FB9F 8D  0A             PAC1    BSR     PACK            PACK 4 INTO 3
FBA1 6A  61                     DEC     1,S             LS COUNT
FBA3 26  FA                     BNE     PAC1
FBA5 6A  E4                     DEC     0,S             MS BYTE
FBA7 26  F6                     BNE     PAC1
FBA9 35  86                     PULS    D,PC            CLEAN UP STACK,RETURN

FBAB EC  81             PACK    LDD     X++             GET FIRST TWO CHARACTERS
FBAD 58                         ASLB
FBAE 58                         ASLB
FBAF 58                         ASLB
FBB0 49                         ROLA
FBB1 58                         ASLB
FBB2 49                         ROLA

                        * ACCA IS NOW PACKED AND ACCB CONTAINS 4 BITS
                        *           LEFT JUSTIFIED

FBB3 A7  A0                     STA     Y+              STORE FIRST PACKED BYTE
FBB5 A6  80                     LDA     X+              GET THIRD CHAR.
FBB7 44                         LSRA
FBB8 44                         LSRA
FBB9 84  0F                     ANDA    #$0F            CLEAN UP MS NYBBLE

                        * ACCA HAS MS NYBBLE AND ACCB HAS LS NYBBLE

FBBB 34  04                     PSHS    B               PUT B IN TEMP STORAGE
FBBD AA  E0                     ORA     S+              PUT CHAR TOGETHER, CLEAN STACK
FBBF A7  A0                     STA     Y+              STORE SECOND PACKED BYTE
FBC1 EC  81                     LDD     X++             GET LAST TWO CHAR.

                        * PICK UP 2 LSB FROM A AS 2 MSB IN B

FBC3 58                         ASLB
FBC4 58                         ASLB
```

```
FBC5 44                 LSRA
FBC6 56                 RORB
FBC7 44                 LSRA
FBC8 56                 RORB
FBC9 E7   A0            STB     Y+          STORE THIRD PACKED BYTE
FBCB 39                 RTS


                ************************************************


FBCC 34   20    UNPAKS  PSHS    Y
FBCE 4C                 INCA                ADJUST COUNTER MS BYTE
FBCF 34   06            PSHS    D           PUT COUNT ON THE STACK
FBD1 8D   0A    UNP1    BSR     UNPACK      UNPACK 3 INTO 4
FBD3 6A   61            DEC     1,S         LS COUNT
FBD5 26   FA            BNE     UNP1
FBD7 6A   E4            DEC     S           MS COUNT
FBD9 26   F6            BNE     UNP1
FBDB 35   A6            PULS    D,Y,PC      CLEANSTACK,RETURN

                * UNPACK RETURNS FOUR RIGHT-JUSTIFIED 6-BIT
                * CHARACTERS FROM THREE PACKED 8-BIT BYTES

FBDD 34   06    UNPACK  PSHS    D           SAVE D REGISTER
FBDF EC   80            LDD     X+
FBE1 44                 LSRA                ;
FBE2 56                 RORB                ; 16-BIT SHIFT, TWO PLACES
FBE3 44                 LSRA                ;
FBE4 56                 RORB                ;

                * ACCA IS NOW UNPACKED

FBE5 54                 LSRB
FBE6 54                 LSRB

                * ACCB IS NOW UNPACKED

FBE7 ED   A1            STD     Y++         STORE 1ST AND 2ND CHARS
FBE9 EC   80            LDD     X+          GET 2ND AND THIRD BYTES
FBEB 58                 ASLB                ;
FBEC 49                 ROLA                ; ANOTHER SHIFT, TWO PLACES
FBED 58                 ASLB                ;
FBEE 49                 ROLA                ;
FBEF 84   3F            ANDA    #$3F        CLEAR TOP 2 BITS

                * ACCA IS NOW UNPACKED

FBF1 E6   80            LDB     X+          GET 3RD BYTE AGAIN
FBF3 C4   3F            ANDB    #$3F

                * BOTH ARE NOW UNPACKED

FBF5 ED   A1            STD     Y++         STORE THIRD AND FOURTH CHARS
FBF7 35   86            PULS    D,PC        RECOVER D, RETURN


                        END
```

```
0 ERROR(S) DETECTED

SYMBOL TABLE:

PAC1    FB9F    PACK    FBAB    PACKS   FB9C    UNP1    FBD1    UNPACK FBDD
UNPAKS FBCC
```

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10. SUPPLEMENTARY NOTES

FHWA Contract Manager: Y. P. Virmani

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)

The progress on a research program directed at developing a nondestructive method for measuring the corrosion of steel in concrete as related to bridge deck deterioration is reported. This report summarizes the past work and describes the new developments on this project. The five phases described are: 1) a literature review, 2) preliminary studies, 3) measurements in concrete, 4) field measurements, and 5) development of a microprocessor system.

12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)

Bridge deck corrosion; corrosion in concrete; corrosion of steel, polarization technique; rebar corrosion.

13. AVAILABILITY

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